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Inside Audi's next generation of ICE models

OUTSIDE THE BOX
Mopar takes the crate motor concept electric

IN COMMAND
Control is key to ensuring refinement in electric drives

CHAIN REACTIONS
Understanding battery supply constraints

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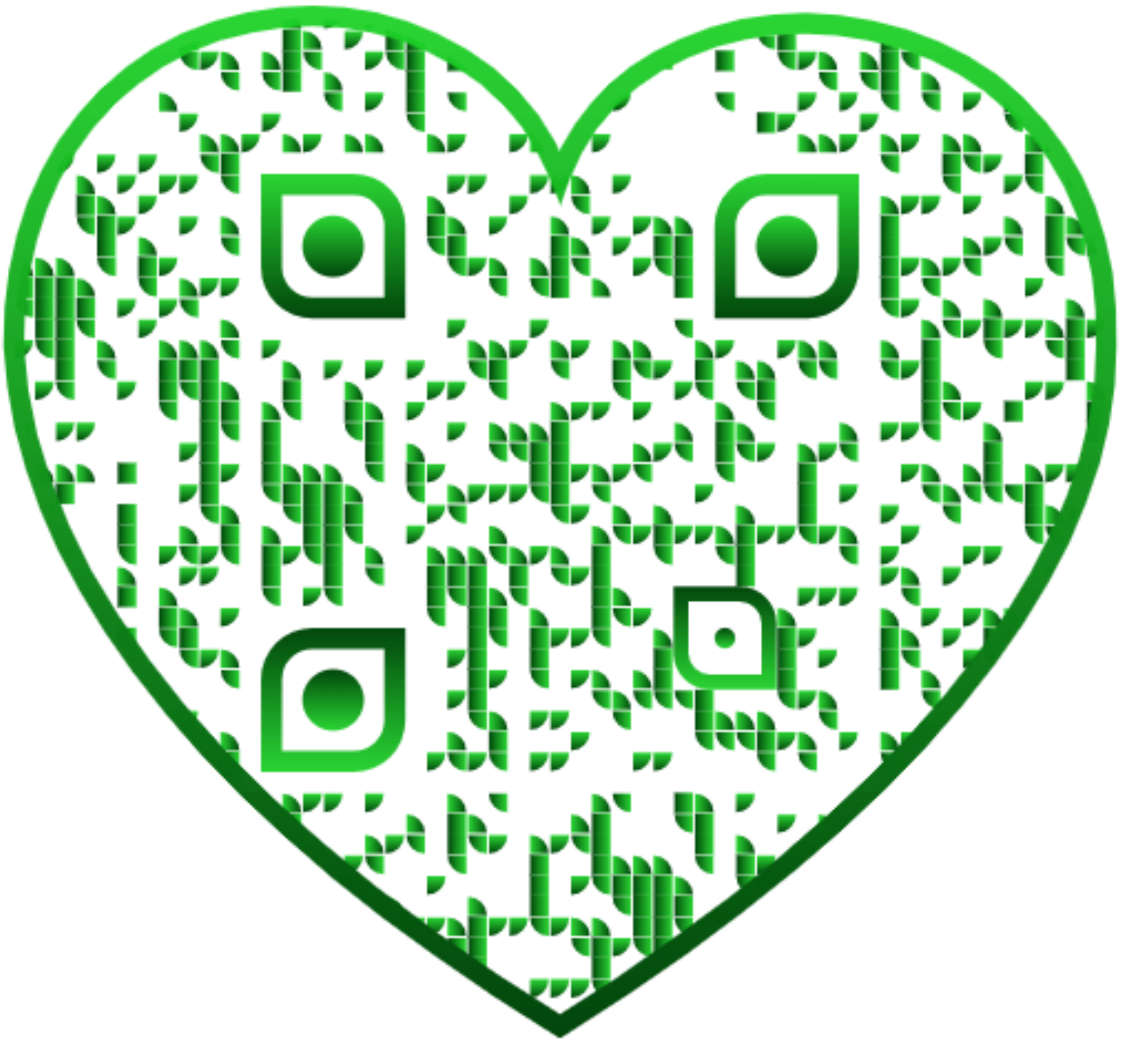

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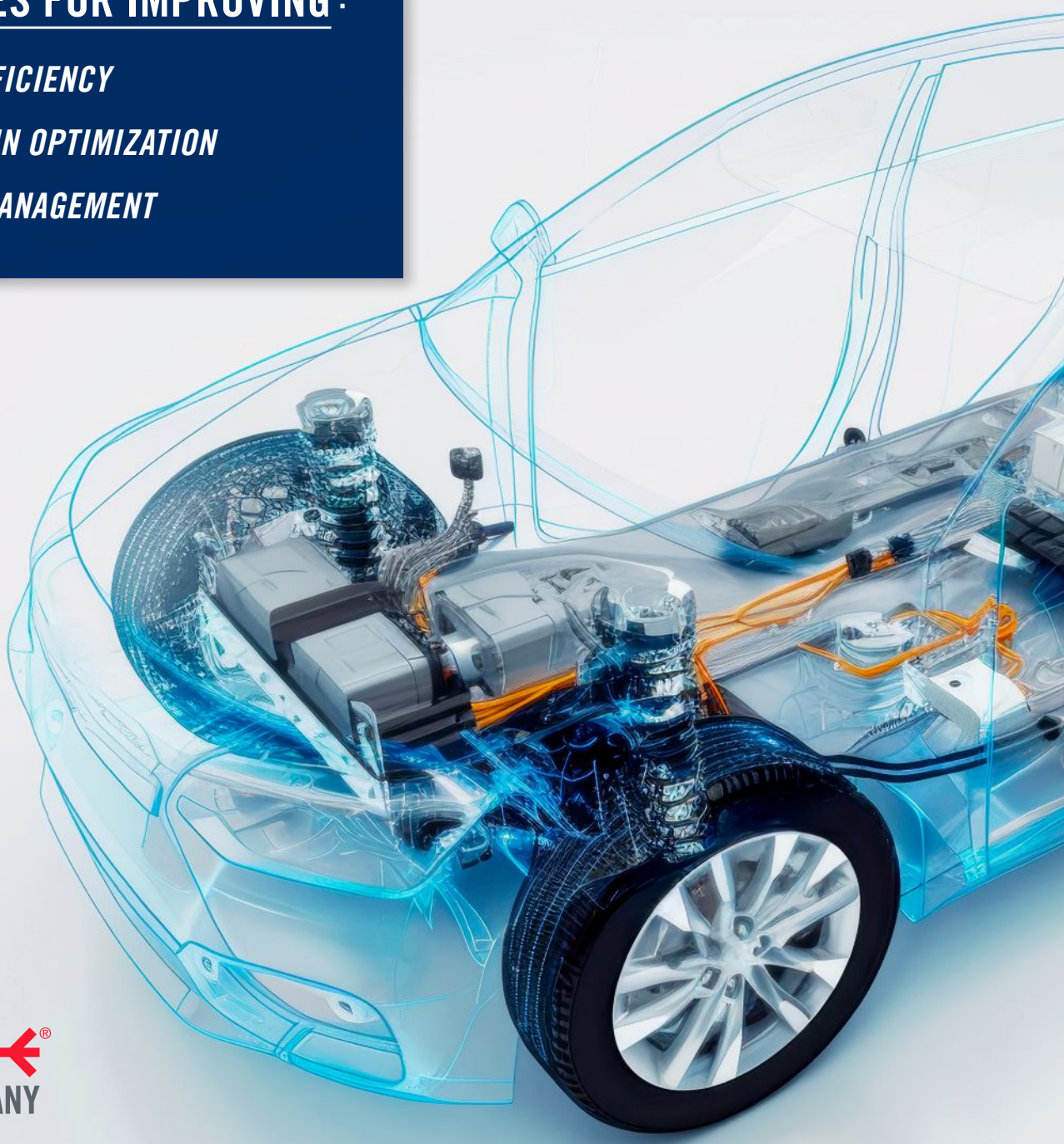

THE LEE COMPANY

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EDITORIAL
Editor: Lawrence Butcher
Web editor: Adithya Gopal

Production editor: Alex Bradley
Sub editors: Sarah Lee, Alasdair Morton, Mary Russell

CONTRIBUTORS TO THIS ISSUE
Gemma Hatton, Graham Heeps, Chris Pickering, Mark Smyth, Michael Taylor, Wayne Ward

DESIGN
Art director: Craig Marshall
Art editor: Ben White

PRODUCTION
Production assistants: Dylan Botting, Amy Brown

COMMERCIAL
Publication director: Simon Edmands (simon.edmands@ukimediaevents.com)

DATA
Head of data: Lauren Floyd

MANAGEMENT
Chairman: Tony Robinson
Managing director: Colette Tebbutt
Managing director, magazines: Anthony James

CONTACT US
Automotive Powertrain Technology International
Parsonage House, Parsonage Square, Dorking, RH4 1UP, UK
Tel: +44 1306 743744
www.automotivepowertrain technologyinternational.com
Prefer to receive a digital copy? Email datachanges@ukimediaevents.com

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Editor's note

This issue of *APTI* has a distinct electrification bias to it, with in-depth dives into the intricacies of motor control and the new kid on the semiconductor block – GaN. On a grander scale, we take a big-picture view of the battery supply chain.

While the mining of critical elements such as lithium and copper may seem far removed from the micron-level intricacies of semiconductor manufacturing, the demands for the former are intrinsically linked to the latter.

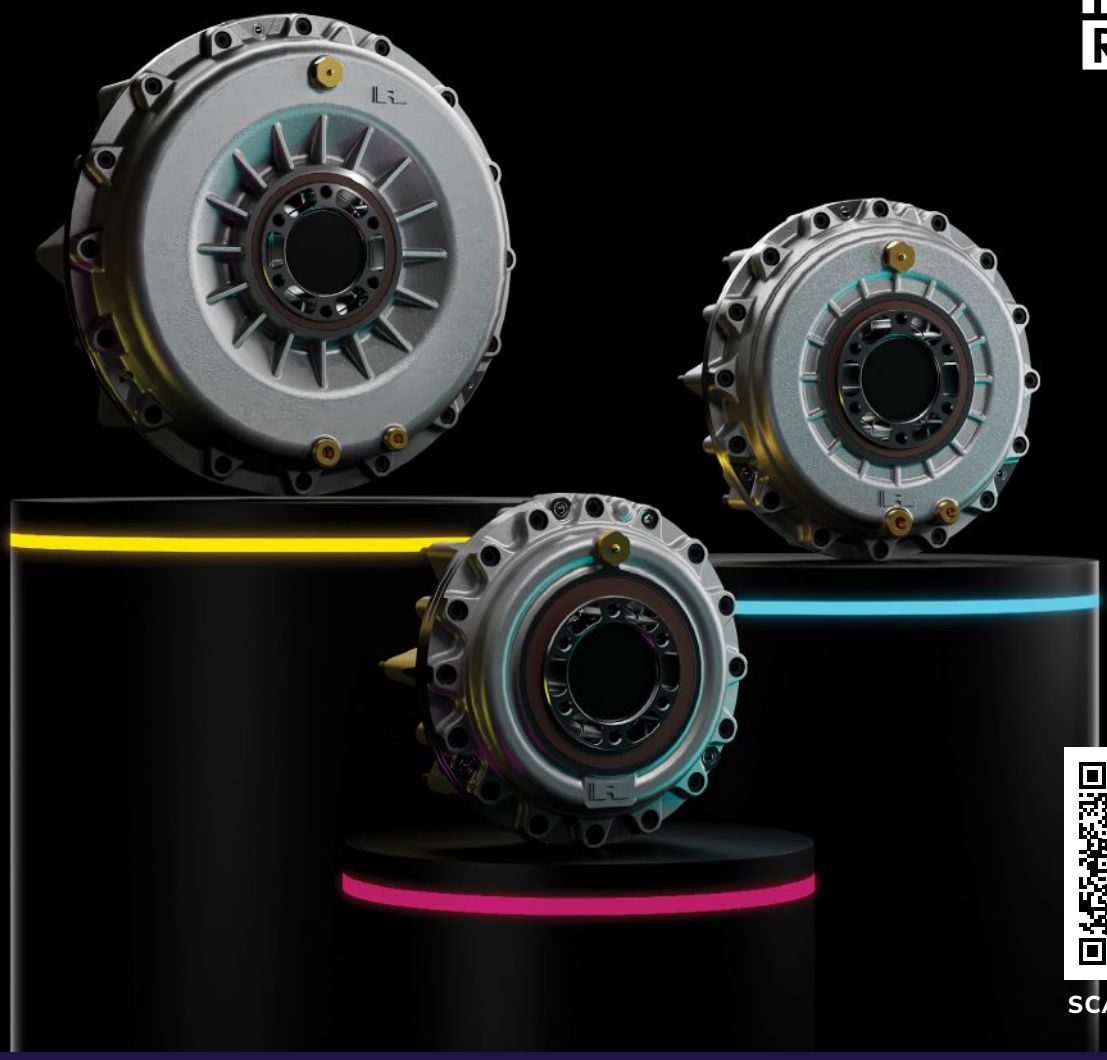
Progress in power semiconductor technology, from the silicon IGBTs of a decade ago to the next-generation GaN devices currently under development, has been phenomenal. As the capabilities of inverters employing these devices have increased – greater power handling, ever faster switching and, ultimately, increased efficiency – so too have the options for motor control. It's a virtuous circle, with knock-on effects for the entire supply chain.

More efficient and powerful inverters enable more precise control of motors, helping to reduce losses and thus reduce heat rejection demands. Motors can be made smaller for a given power and require less cooling, helping to trim overall vehicle mass, and the increased efficiency means less battery capacity is needed to hit range targets. Though these gains may seem small – we're talking perhaps 5-7% at a system level if comparing the best silicon-based 400V architectures with SiC 800V systems – they are significant when looking at hundreds of thousands of units. The potential for GaN to bring SiC performance at a silicon price could see such performance acceleration trickle down to even the lower rungs of the automotive market.

Of course, better power electronics will not answer all the challenges manufacturers are facing in their electrification supply chains. One must not forget that semiconductors are also subject to their own constraints (remember 2021?) and there are few chip foundries in the world capable of producing the products automotive needs (not to mention that their skills are in demand across a host of other industries). However, when viewed alongside various other powertrain developments, such as new battery chemistries and moves by some manufacturers toward more localized production, they form an important part of the supply chain resilience jigsaw.

Lawrence Butcher

RICARDO



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TWO AND TWO MAKES FIVE

AUDI'S LATEST COMBUSTION ENGINE PLATFORM BENEFITS FROM A MILD HYBRID SYSTEM WITH A NEW POWERTRAIN GENERATOR

Words: Mark Smyth

Audi is ushering in a new era for its A4, an era in which it will no longer be called the A4 at all, but the A5. This isn't as odd a decision as it might sound. The OEM is reorganizing its line-up so that models with even numbers are battery electric and those with odd numbers retain a combustion engine, in most cases with some form of electrification.

This does not mean that the A4, which has a lineage going back to the original Audi 80 of the 1960s, is dead, but rather is being reborn as an electric model yet to be revealed. Admittedly, the new A5 sedan is for all intents and purposes still the A4, but let's just call it a marketing strategy and leave it there.

The new A5 uses Audi's latest platforms, which also underpin the new Q5 SUV. While the upcoming A4 will sit on Audi's new Premium Platform Electric (PPE), the same as the latest Q6 E-tron, the powertrains of the A5 models will be part of the Premium Platform Combustion (PPC), unsurprisingly a platform for gasoline and diesel models.

Dieter Seebach, in charge of powertrain development at Audi, says the new platforms will facilitate the brand's move to create more software-defined vehicles, especially when it comes to infotainment and driver assistance regulations.

"In our new projects we are deciding between PPE and PPC," he explains. "The main goal was that both platforms use the same E3 network architecture. We changed the combination of control units, how they work together, and we tried to have a basic architecture that can be used for both systems. We also want to integrate all the other things, like the infotainment system, at the same level."

The outgoing platforms relied on just one engine control unit (ECU) but the new platforms split responsibilities across five high computing performance (HCP) units.

"We saw in the last few years that our ECUs that we had on board came to a limit," Seebach says. "They were limited in their power and so we decided to make a new network where we are now prepared for the future."

Only one of those HCPs is dedicated to powertrain management, and that is mainly just to handle torque flow. It's the same HCP in both the combustion and the electric platform but it must manage different levels of torque demand. In the combustion engine models, ECUs are retained for the transmission and engine controls, but moving more of the functionality into HCPs also enables faster software changes during development and during the lifecycle of a vehicle through over-the-air updates.

To keep costs down for fleet customers, entry-level gasoline models have no electrification, except for the starter generator. Move further up the range and you find the new MHEV Plus system, which extends the role of a traditional mild hybrid to provide a limited amount of fully electric range.

HYBRID OPTIONS

It's a 48V system that combines a riemengetriebener starter generator (RSG) with a newly developed powertrain generator. The RSG enables the engine to start at a higher speed, removing the traditional cranking issues associated with a standard starter generator. The powertrain generator is then installed at the end of the transmission and allows fully electric driving for parking maneuvers and other uses.

The same powertrain generator is used for the more powerful Audi S5, where it is combined with a V6 gasoline engine. The same functionalities are applied but software changes are made to adjust for the higher level of torque from the engine. MHEV Plus also allows for the use of a dual clutch transmission for the first time in the S5. Traditionally a torque converter transmission has provided a greater benefit at low engine speeds, but Seebach says that with MHEV Plus now providing the initial torque, they were able to make this transmission change.

1

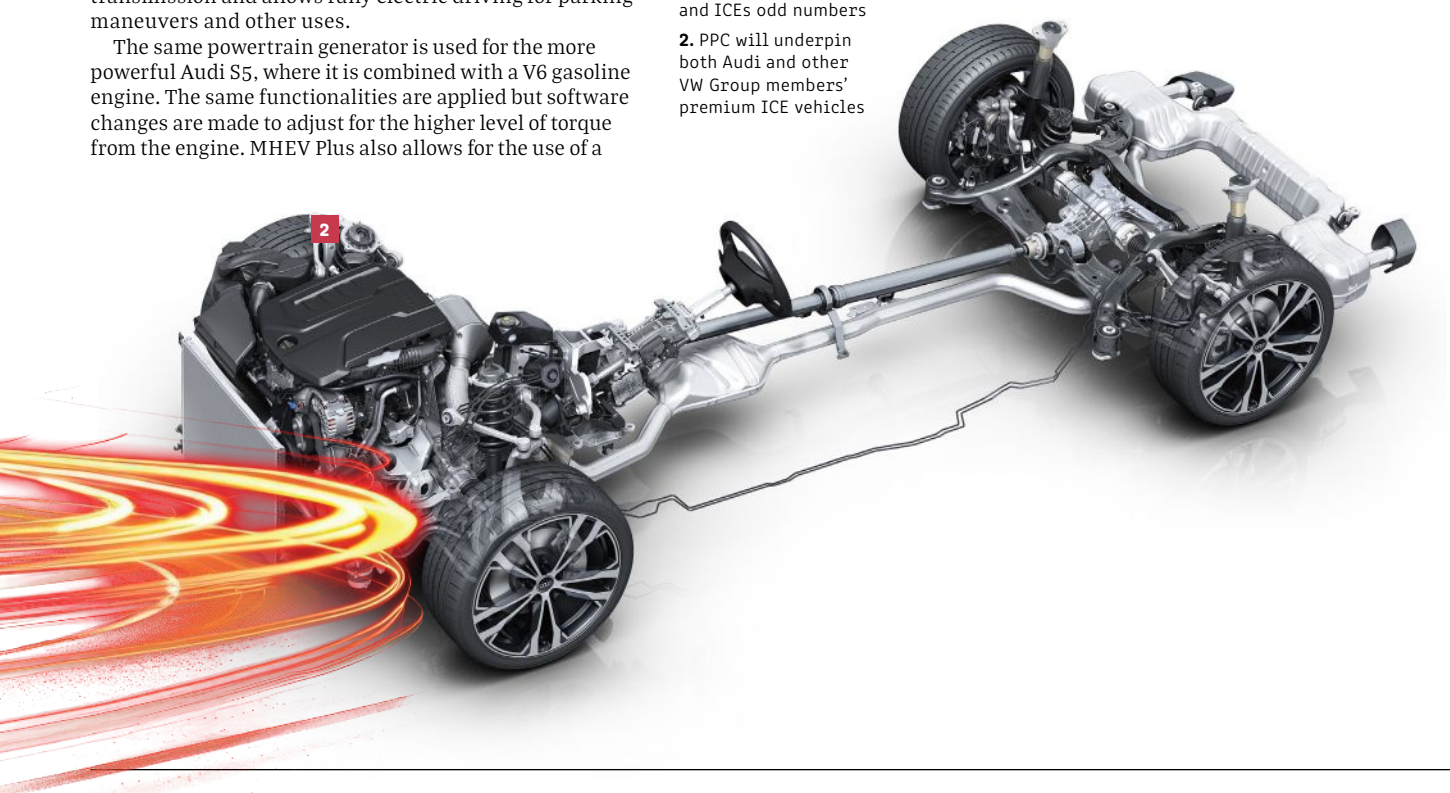
PHEV FUTURE

Plug-in hybrid versions will be added to the A5 range in 2025, but Seebach believes it is essential to have both PHEV and MHEV Plus to satisfy the needs of different customers when it comes to costs. At the same time, both powertrain options allow Audi to meet different market requirements around the world in terms of emissions reductions and costs. He sees this multiple powertrain approach as both exciting and challenging.

"On the one hand it is more interesting because you have different technical equipment that you have to try to optimize," he says. "Every setup has its own benefits but also its own drawbacks. You might think the PHEV system is more complicated than MHEV Plus. It's actually the opposite because with the PHEV system you have just one electric motor that speeds up the engine and enables electric driving. In the MHEV Plus system you have

1. Audi's new EV-only models will get even-number designations, and ICEs odd numbers

2. PPC will underpin both Audi and other VW Group members' premium ICE vehicles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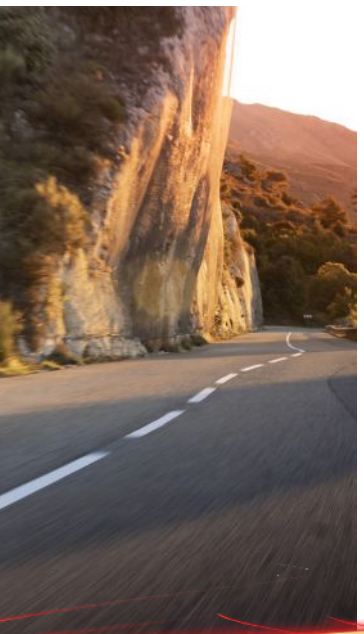


THE MHEV PLUS GENERATION

Audi has been using mild hybrid systems for years, but it sought fresh ideas to create the new MHEV Plus system.

Daniel Reichert was responsible for the development of the MHEV Plus technology and was approached while still at university. He balanced studying with work at Audi before joining the OEM full time to initially work on the new powertrain generator.

Work on the production version began two years ago with two main objectives: reducing fuel consumption and providing sportiness. A reduction in consumption is easily measured, but how does Reichert define sportiness?

"We have measurements such as 0-100km/h, but it's how it feels when you drive it," he says. "That's not measurable, but you can feel it and you have a feeling for how the car compares with the old model. That's how we developed it."

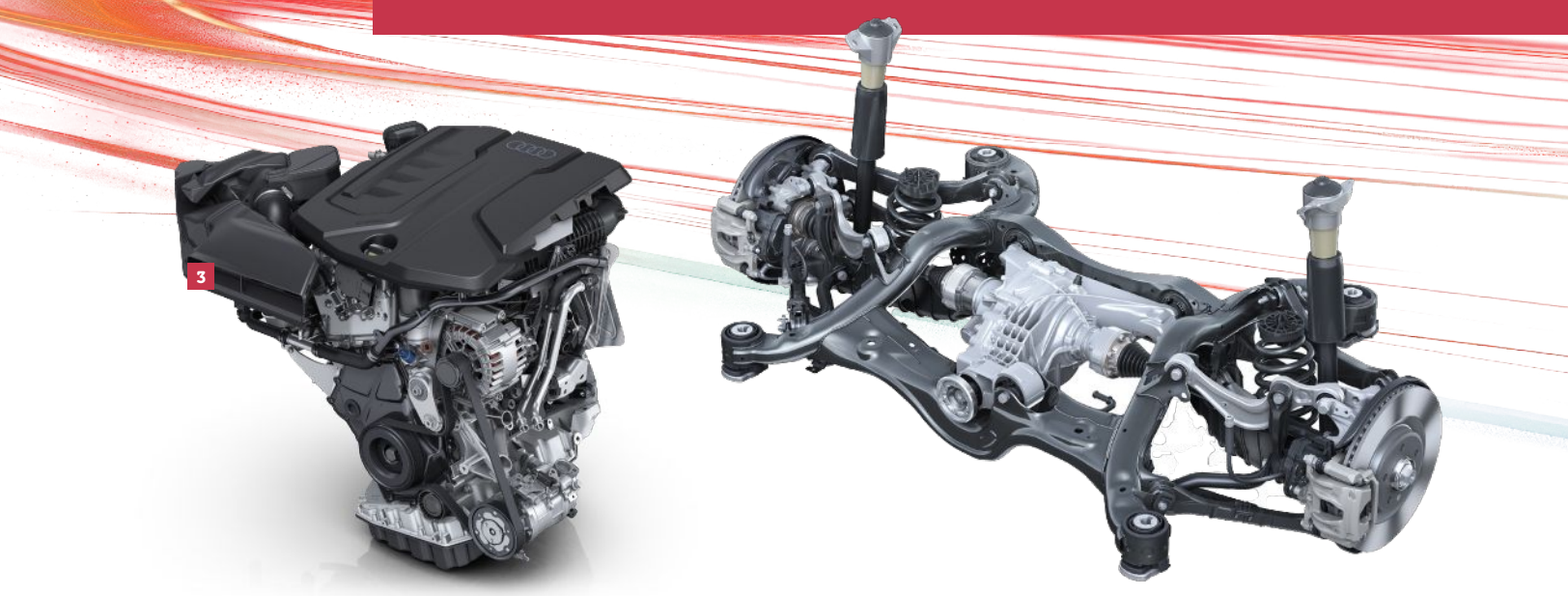
Along the way there were several challenges, including not allowing the 18kW and 230Nm of torque from the powertrain generator to make things too sporty.

"We didn't have a system like it before and it is quite complicated compared with other MHEV systems," he says. "It's not a PHEV where you have full electric range and a big electric motor with more than 100kW, so the range where you can use it is quite narrow. We had to do a lot of testing and we had to simulate quite a bit. It was quite tricky to find a good spot between fuel consumption and responsiveness and sportiness.

"It's challenging to get the engine to start and stop with a high level of comfort," he continues. "In the first development phase, we had targets for sportiness, like the 0-100km/h time, and it fulfilled all the criteria. Then we took it for a test drive, and it was not driveable. It kept turning the engine on and off and it was terrible."

Eventually that issue was overcome and the team have now achieved a smooth harmony between the engine and the powertrain generator. It's been a great learning curve for Reichert and a chance to make his mark early in his career.

"It was really interesting and a lot of fun to develop because it was really new and the older colleagues didn't have any experience with it. That meant that younger colleagues like me had a chance to get started in the world."



3. Audi's latest version of the EA888 will be the stalwart of its PPC offerings, with improved efficiency and a revised hybrid to keep up with evolving emissions regulations

two electric engines: the RSG, which starts the engine and provides some recuperation, and the powertrain generator. You have to check three torque suppliers: the RSG, the powertrain generator and the internal combustion engine. It's even more complicated, but from a technical point of view it is very interesting to work on all these things. However, it is challenging because you have to try to find synergies so that you do not need to develop each vehicle individually in order to be able to optimize your workload."

Ultimately the two platforms will allow the powertrain engineering teams to do just that. They will provide the OEM with the freedom to develop specific models for each market and to meet the demands of different customers. The platforms also allow for sedans, coupes, crossovers and SUVs, again to suit different market needs. While the architecture will remain the same, it will be software that is used to define many of the characteristics of each model as Audi, like most of its rivals, transitions through the next decade. ◉

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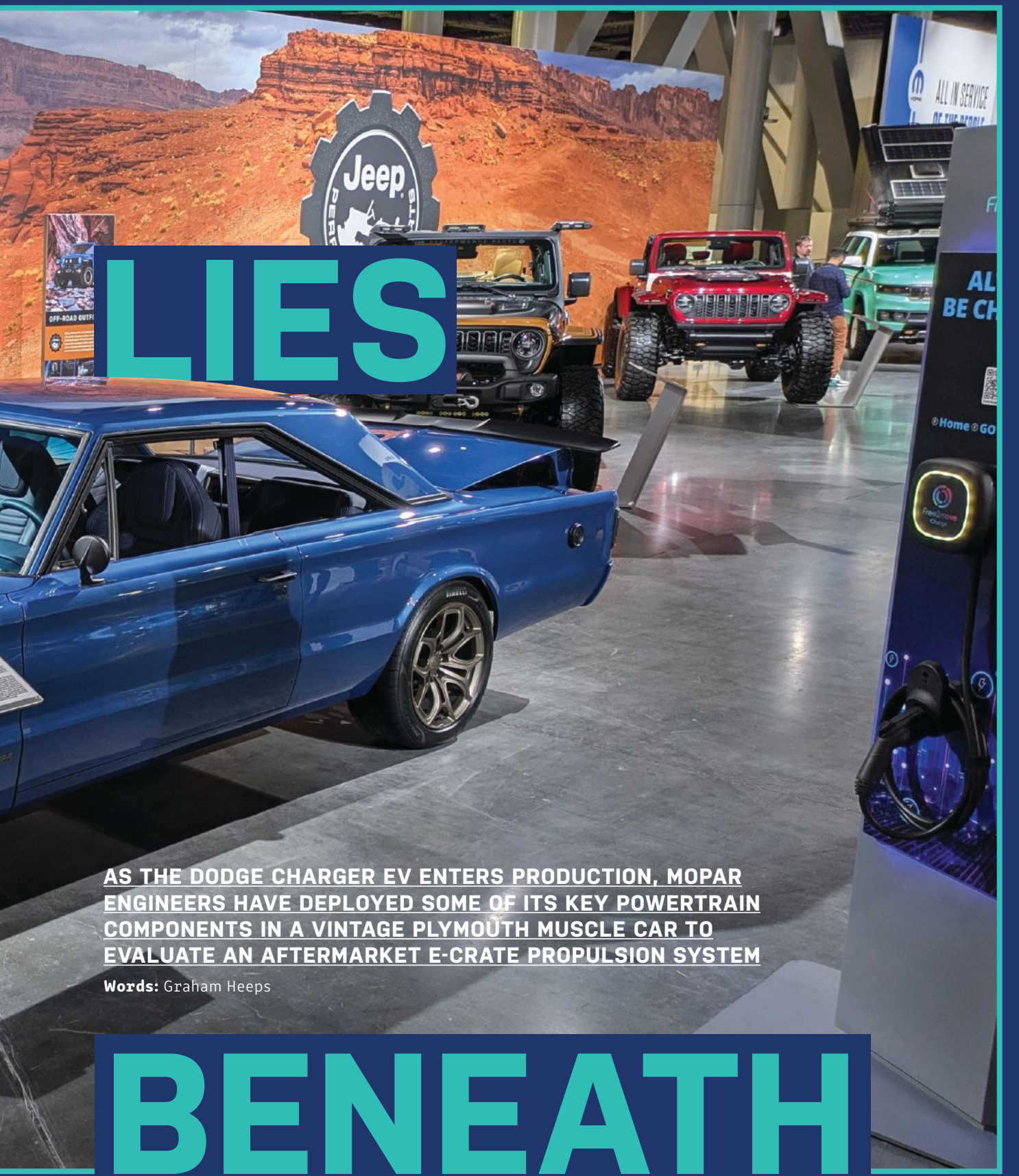

LIES BENEATH

AS THE DODGE CHARGER EV ENTERS PRODUCTION, MOPAR ENGINEERS HAVE DEPLOYED SOME OF ITS KEY POWERTRAIN COMPONENTS IN A VINTAGE PLYMOUTH MUSCLE CAR TO EVALUATE AN AFTERMARKET E-CRATE PROPULSION SYSTEM

Words: Graham Heeps

The annual SEMA Show has evolved in recent years to include the growing EV-swap or 'electromod' segment, with custom car shops and individual builders recognizing the performance and reliability potential of updating classic rides with an electric powertrain. In previous years, Chevrolet and Ford have displayed their electric crate motor (e-crate) offerings in the Las Vegas halls; this year it was the turn of Stellantis's parts, accessories and service division, Mopar.

The showstopping choice of vehicle was the 1967 Plymouth GTX Electromod Concept. With the new Dodge Charger EV soon to reach customers, a team managed by Mopar North America's head of parts and accessory engineering, Neil Young, has spent the past couple of years assembling a potential e-crate package around a core of production-ready Charger parts. The goal is to gather feedback from enthusiasts who would drive the finished conversions, the custom car shops and professional assemblers who would install the parts, the Mopar engineers solving the technical challenges and the executives who would sign off on a commercial launch.

> "Other than the battery, the critical components are basically production parts. We're trying to leverage what we've learned with our Hemi [ICE] crate packages"

2. HEMI-CLONE
In one of the Mopar team's studies, the e-crate setup matched the torque figures of a 5.7-liter (345ci) Hemi across all speed ranges except for in first gear

FROM CHARGER TO GTX

Torque from the 335hp (250kW) electric drive module (EDM), mounted north-south in the GTX, runs to a classic 8¾ rear end through a 3:1 reduction gear. The EDM comes straight from the Charger, as do the inverter and integrated dual-charging module (IDCM).

"Other than the battery, the critical components are basically production parts," Young confirms. "We're trying to leverage what we've learned with our Hemi [ICE] crate packages. If we were to do this, I think there's a lot of value in offering something that has the reliability and durability of production parts. Plus, the volumes make it less expensive."

The EDM and IDCM are both painted in gloss Mopar Blue, evoking the turquoise of R/RB big blocks past. Together with a custom-styled, silver IDCM cover that nods to the Hellcat's supercharger, the GTX has a level of engine-bay pizzazz rarely found under the hood of an EV.

Other production parts on the build include a vacuum pump from a Jeep Wrangler 4xe for the brake system, power steering pump and coolant pump, plus the rotary shifter from a Dodge Durango, although the GTX does not shift as such. An important custom element are the isolated motor mounts for the EDM – two vertical and two lateral. The mounts are designed with ease of manufacturing in mind. Each brace or bracket is designed to be cut by water jet from 6061 aluminum alloy. There's no doubt that the bracketry adds to the under-hood aesthetic.

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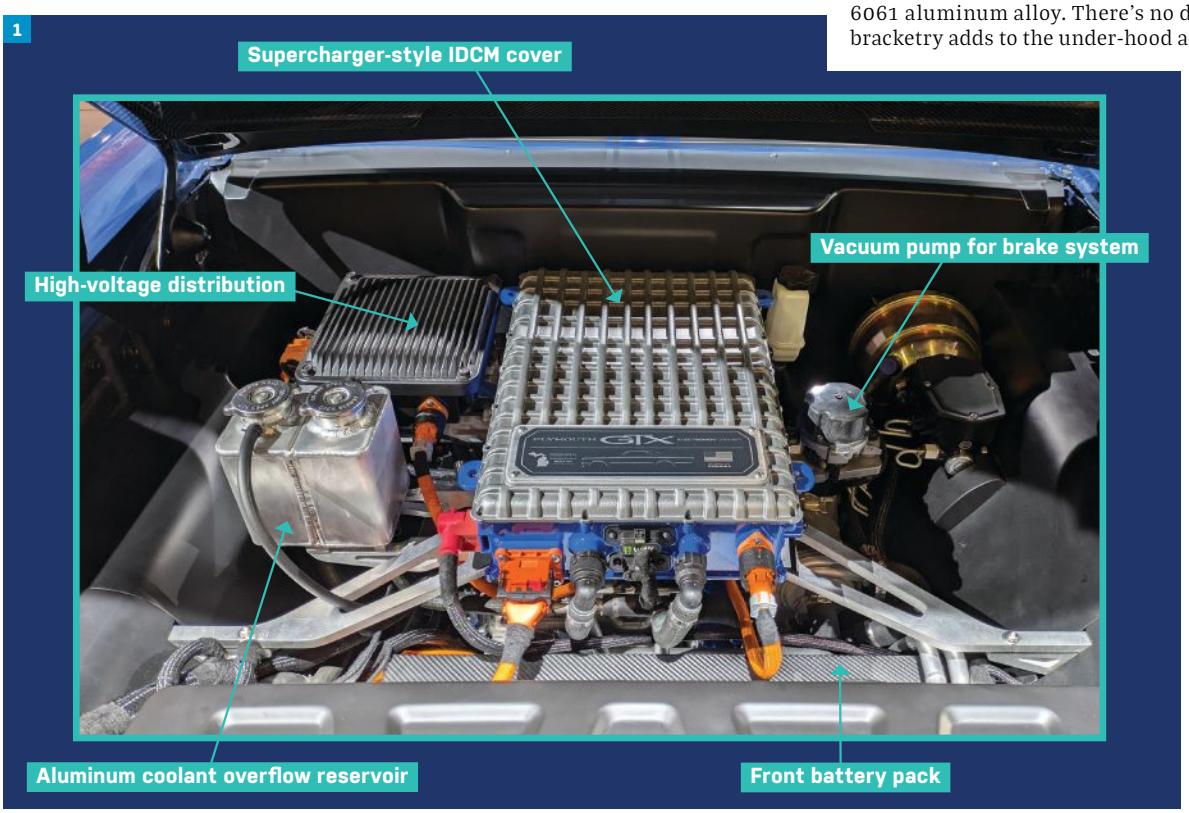

1. IMAGE IS EVERYTHING
The Mopar team has gone to great lengths to lend the e-crate visual appeal

2

BATTERY DISCUSSIONS

The high-voltage electrical system was pegged at 400V to match the performance of the motor and maximize commonality with the production car, while the battery pack was sized at 73kWh for a range of around 320km. Whether a production pack would match those figures is exactly the sort of question on which Mopar wants input from the aftermarket community, as Young explains.

"We had a lot of initial discussion about range and mileage, and how we'd achieve it," he says. "As a result, we picked a lithium-ion chemistry, but using our own internal batteries would be very challenging at the moment. Maybe we can do that later, but the production battery cells, systems and modules are currently set up for a long area underneath the car, in between the wheels. When we looked at that [in the context of the Plymouth], we knew that would be very challenging, so we went with an aftermarket partner."

He declines to name the supplier, as no decisions have been made on a production partner. The complete pack incorporates 384 pouch cells lying on their sides, split between one pack low in the engine bay ahead of the electric motor, and three in the trunk, where they are encased in a neat structure with the liquid cooling system.

In the front of the car, the pack benefits from one of two under-hood cooling circuits. Working backward from the grille, the first low-profile thermal rejection module (radiator) is for the battery cooling loop, given that it needs to be kept in the tightest thermal window. That's followed by another radiator to cool the motor charger, and finally by a row of cooling fans.

"This pack has quite a bit of range," he continues. "When you talk to customers about buying EVs as regular drivers, range anxiety is a big deal. But for a lot of people we have talked to about this [project], range is not as critical. We are finding out that if it were 120 miles [193km], they'd be fine. So maybe the

DEALING WITH ELECTRIC POWER REQUIRES A DIFFERENT APPROACH TO TRADITIONAL ICE CRATE OFFERINGS

SOME ASSEMBLY REQUIRED

Apart from the motor mounts, Neil Young identifies the high-voltage wiring and its associated connection systems as the biggest challenge facing would-be e-crate installers. He says, "The shielding around the high-voltage wires is extremely important and the connectors are extremely complicated in the way they clamp around that shielding, so we're talking to assemblers, too." The lengths of the necessary wires, the potential need for cuts or splices, and the final location of the charge port – given the likelihood of a battery pack in the trunk – are all topics of discussion.

EASY SERVICE
The three trunk-mounted battery packs are enclosed in a custom-built, cartridge-style aluminum frame that's designed for easy removal during service or replacement

future is half the pack. You'd lose a lot of weight and get a little more performance. We're also going to look again at the chemistry from a power-to-energy viewpoint."

The pack recharges via a conventional J1772 connector that hides beneath a flip-top, fuel-cap-style door in the rear fender. The team has not identified a customer need for DC fast-charging in the electromod application.

"The DC fast-charger adds a whole additional level of risk when you're dealing with smaller battery suppliers," Young says, adding that in any case, conversations with owners who drive their classics long distances have revealed that they are more likely to favor an ICE. He notes that those owners also tend to drive their cars less frequently and therefore have fewer concerns about reliability or the car failing to start – both areas where an EV swap offers advantages over an aging ICE.

TUNING AND TESTING

The battery management system was recommended by the battery supplier. Young says that in the interests of safety, Mopar is happy to go that route for now, rather than doing its own. "It might be something to look at in the future. We'll see what feedback we get."

The third-party ECU is likewise a departure from the Charger's production item and from the Hemi crate-motor precedent.

"There's so much more in that [production] ECU. With the people that do these conversions being enthusiasts rather than someone just looking for transportation, we think they would appreciate it if we gave them something that's a little closer to a tuner [control module], rather than a production module that's buttoned up because all the secrets are in it. When we did this build, we felt it made sense to go more of the tuner route. People can order something they could start tweaking themselves. We can lock the safety aspects of it, so they're not shifting strange, coming up with different gears or getting accidental accelerations. But for the other stuff, let them play with it."

Young's team has been honing the prototype e-crate setup using a twin of the GTX's powertrain that the development team fitted to a 1967 Plymouth Belvedere. That car was previously known as the 'Hellvedere', having served as the testbed for the Hellcrate 6.2-liter supercharged crate engine program. After extensive testing, Young reports that the electric muscle car is now a lot of fun to drive: "It's nostalgic, and 335hp is plenty." Nevertheless, the calibration is less complex than it would be for a mass-production program.

"The team is so focused on efficiency because the range is so critical for daily driving," he observes. "Driving and charging efficiency are a big deal, whereas I don't think they're as significant for us in this case. We focus more on driveability. Regeneration is another huge activity on the production side, but it's simpler here. Those guys have to design a vehicle that works for hundreds of thousands of customers, but our goal is just to have it flexible to the assembler or the builder. Maybe they can have a switch to go between aggressive and less aggressive. It tends to be a different type of customer from our perspective."

> "The DC fast-charger adds a whole additional level of risk when you're dealing with smaller battery suppliers"

At the time of writing, the team was completing reliability testing ahead of rotating the Belvedere through the executive body for their evaluation.

"We're also updating it," Young says. "One of the pleasures of picking a production product that's not in production yet is it keeps getting better! But sometimes better means change and then we have to verify whether our software supports the change or not, so we're updating the software in all the major modules and checking whether the diagnostics work. We are going to provide a lot of diagnostics associated with the production-like parts. That's something else you might not get from an industrial motor with a lot of power [a popular choice for electromod builders]. That'll be a huge benefit both to an installer and to someone trying to maintain the vehicle and service it." ⦿

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HYUNDAI IONIQ 5N

Dual PMSM

Vital Statistics

Motors: Front and rear PSM
Battery chemistry: NMC
Capacity: 84kWh
Power output: 478kWh
Peak charge: 350kW
WLTP range: 447km

The current crop of EVs are undoubtedly exceptionally capable vehicles, providing ever-increasing range, excellent refinement and high levels of tech. However, very few could be considered fun. Having driven a decent spread of different manufacturers' offerings, from small hatches to sports saloons, the only one to have provided true 'fun' – as in a sense of engagement and entertainment beyond arresting acceleration – was Honda's now defunct E. Though even that fun was tempered by the little E struggling to do more than 160km per charge on a chilly day.

With this in mind, I approached Hyundai's first crack at an N variant of the successful Ioniq 5 with no small degree of skepticism. Not least because it comes with the option of fake engine noise and synthesized gearchanges. It's bad enough when manufacturers pipe synthetic exhaust notes into ICE cabins; surely an EV pretending to be a throaty ICE would be a terrible letdown?

How wrong I was. Within five minutes of hopping into the 5N, I was hooting and hollering like an 18-year-old in a Mk2 Golf GTI (albeit one with 650bhp), relishing every burble of downshift and pull through the 'gears'! Hyundai's engineers have done an exceptional job of mapping the behavior of the powertrain to mimic an ICE, elevating the driving experience to another level and involving the driver in a way that other EVs can only dream of.

The underpinnings of the Ioniq have been heavily revised to ensure both the powertrain and chassis are able to cash the soundtrack's checks. The dual permanent magnet motors can run at up to 21,000rpm, the front producing 166kW, the rear 282kW, and feature direct cooling of the rotor and stator, enabling extended operation at high power. The electrical architecture is 800V and the motors use hairpin windings; control is handled by a dual-inverter setup using SiC power electronics to increase power density and ensure durability under extreme use. The chassis has been reinforced with additional welds and extra structural adhesive, providing a stiffer platform for the uprated suspension.

These mechanical systems work in conjunction with various electronic aids to improve the dynamic experience. For example, there is the N Torque distribution (NTD), which enables the drive bias to be shifted from front to rear, and an electronic LSD at the rear axle. Braking performance has not been ignored and up to 0.6*g* of deceleration can be achieved using regen alone. The brake-by-wire system is also harnessed for the N Pedal, which uses increased regen on the rear axle to initiate weight transfer on turn-in.

The overall result is deeply impressive. Despite not being small, the Ioniq 5N hides its size well, feeling eager and responsive on twisting roads. Importantly, it makes you feel like a part of the performance, rather than just being along for the ride, and for that fact alone it is something of a game-changer in the EV market. **LB**

MASERATI GRECALE TROFEO
V6 twin-turbo

Maserati's Nettuno engine is one of the more interesting ICEs on the market today and equips the flagship versions of the firm's sportscar and SUV offerings. In the case of the Grecale Trofeo, the 3.0-liter V6 produces 530bhp and imbues the two-ton SUV with a 0-100km/h time of just under four seconds – plenty fast enough. The V6, matched with the ubiquitous ZF-supplied 8-speed auto box, provides plenty of drama when required. Superficial as it may sound, the inclusion of generous, all-metal shift paddles behind the wheel adds to the sense of occasion.

The Grecale stacks up well against its performance SUV rivals such as the BMW X3 M Competition, with the exterior and interior styling providing a welcome dose of Italian brio. This is backed up by a chassis that provides decent driver feel and control, though the ride is not quite as compliant as one might like. This is a little odd as the Grecale is air sprung and though the ride is relatively forgiving, it is somehow firm while also lacking composure through bigger compressions.

Unfortunately, although the vehicle is certainly livelier than its German competition, the interior does not feel particularly special and there is plenty of parts bin sharing with other members of the Fiat and Alfa extended family. That said, the infotainment and dash display is easy enough to operate and, beyond the use of a screen for climate functions, pleasant enough to use.

Vital Statistics
Cylinders: 6
Cubic capacity: 3,000cc
Bore/stroke: 88 x 82mm
Compression ratio: 11:1
Power output: 523bhp
Torque: 620Nm

Overall, Maserati's Grecale – in Trofeo trim at least – provides a decent combination of SUV practicality coupled with a potent powertrain for those tempted away from the more run-of-the-mill offerings. **LB**

Vital Statistics BEV
Motors: Front PMSM
Battery chemistry: LFP
Capacity: 61kWh
Power output: 150kW
Peak charge: 80kW
WLTP range: 414km

Vital Statistics ICE
Cylinders: 4
Cubic capacity: 1,600cc
Power output: 183bhp
Torque: 270Nm

OMODA E5 AND 5
PMSM and I4

Differentiating in today's market is crucial, especially for electric vehicles, which, let's face it, often feel similar. In the luxury segment, the finer details make all the difference. Omoda, the luxury brand launched by Chinese manufacturer Chery in 2022, is stepping into this space with two SUV models: the all-electric Omoda E5 and the gasoline-powered Omoda 5.

Interior and exterior elements, build quality and NVH are key factors for any EV. With a dedicated European R&D center focused on chassis tuning, Omoda gave *APTI* high expectations.

So, is the Omoda E5 a game-changer in the BEV market? Equipped with a 150kW (204bhp) electric motor and a 61kWh 'blade' battery, it accelerates from 0-100km/h in 7.6 seconds, generating 340Nm of torque. The WLTP range is 414km, though *APTI* couldn't fully verify this due to limited testing time. According to the manufacturer, the E5 can charge up to 80kW, with a 30-80% charge in just 28 minutes.

Although the range couldn't be fully scrutinized – a key factor for

SUV buyers – *APTI* still found the Omoda E5 to be a solid option. It is well built, comfortable and safe, and comes with some nice little tech features.

In contrast, *APTI* also road tested the Omoda 5, the gasoline variant, which was somewhat disappointing. Powered by a 1.6-liter turbocharged four-cylinder engine, it produces 183bhp (186ps) and 270Nm of torque, reaching 0-100km/h in 7.9 seconds and a top speed of 206km/h. The engine is paired with a 7-speed dual clutch transmission driving the front wheels.

The main drawback of the Omoda 5 was the lag when pressing the accelerator, causing hesitation, especially at junctions. Additionally, the interior felt less refined and NVH was noticeably worse, with road and tire noise throughout the journey.

For these reasons, *APTI* prefers the electric version, which provides a more enjoyable overall driving experience. **RE**

Michael Taylor

"He cares enough to warm it up when a whole generation of drivers can't be bothered, but he just doesn't do it properly"

ABOVE: Long gone are the days of owners fastidiously bringing their automobiles' engines gently up to operating temperature

My father used to religiously start the Ford Falcon (he had a series of them), then set a timer. Said timer would usually, and perhaps conveniently, coincide with the time it took him to make and drink a cup of tea. And eat a bit of shortbread. He could never bring himself to pluck Reverse without a good five minutes of warm-up first, to "let it have a good stretch before it runs".

You know how the Soviet troops used to light fires under their tank engines in the morning during winter in the Second Great Unpleasantness, to unfreeze all the fluids inside the engine? There wasn't much call for that during our 40°C Queensland summers. But that didn't matter to Dad, because ambient temperature was not the critical thing.

It was a habit he picked up from his dad, who got it from his dad, who got it from, presumably, a blacksmith.

I think they all just had a primal urge to make fire and build it bigger, and you could have six or even eight fires in a Falcon, all at the same time. Well, not exactly at the same time, because that would be, in mechanical terms, quite the show, not to mention inefficient, but you know what I mean.

It got worse in winter, when Dad would fire up the big Ford 10 to 15 minutes before it was needed, pumping so many raw hydrocarbon molecules into the frosty air that he could light a match and warm that up, too.

I swear, 15% of Australia's pre-1990s greenhouse-gas emissions were put there by a generation of blokes fastidious about not stressing any metal bits before their time was due. Mind you, 1970s Australian metallurgy didn't discourage that sort of pessimism.

It was almost a crime in winter, because you'd be ready and you'd race outside with Dad, climb in and… wait. And wait and wait some more. On icy vinyl. With no heating, obviously, because that only came from the excess thermal energy that the 4.0-liter six didn't have to spare yet.

Dad's idea was that the car would tell you it was ready when it started to send some heat through the vents, and we were not leaving before that happened. We lied about heat somehow bypassing the front seat to find us in the back, but he never fell for that, and he was uniquely placed to tell.

See, while he warmed up his cars until even the lubricants got bored, he himself wore shorts. All the time.

His legs could discern a 0.1° temperature difference, though no amount of temperature variation, up or down, bothered him. The man avoided long pants so assiduously that he died looking like a skewbald Clydesdale.

I'm reminded of this because where I live, there is a communal parking garage brimming with Euro hatches and SUVs, all of which are thrown into gear the instant the four-cylinder engines catch (though not ours, obviously).

The exception is the Maserati Ghibli, whose owner insists on not only warming up the V8 but also cooling it down at 11pm each night (when he comes home from activities that have had him convicted of organized crime in the past, but that's another story).

He's so proud of his Maserati that he fires it up with a series of enormous throttle blips, with the exhaust butterflies wide open. I've told him that's damaging his V8 more than all the non-warmers are damaging theirs by just instantly cruising off into the slow traffic, not to mention any environmental harm he's unnecessarily causing. But he doesn't seem to care, and that's weird. He cares enough to warm it up when a whole generation of drivers can't be bothered, but he doesn't do it properly, and that infuriates me. I reckon it must be because he never wears shorts. ⦿

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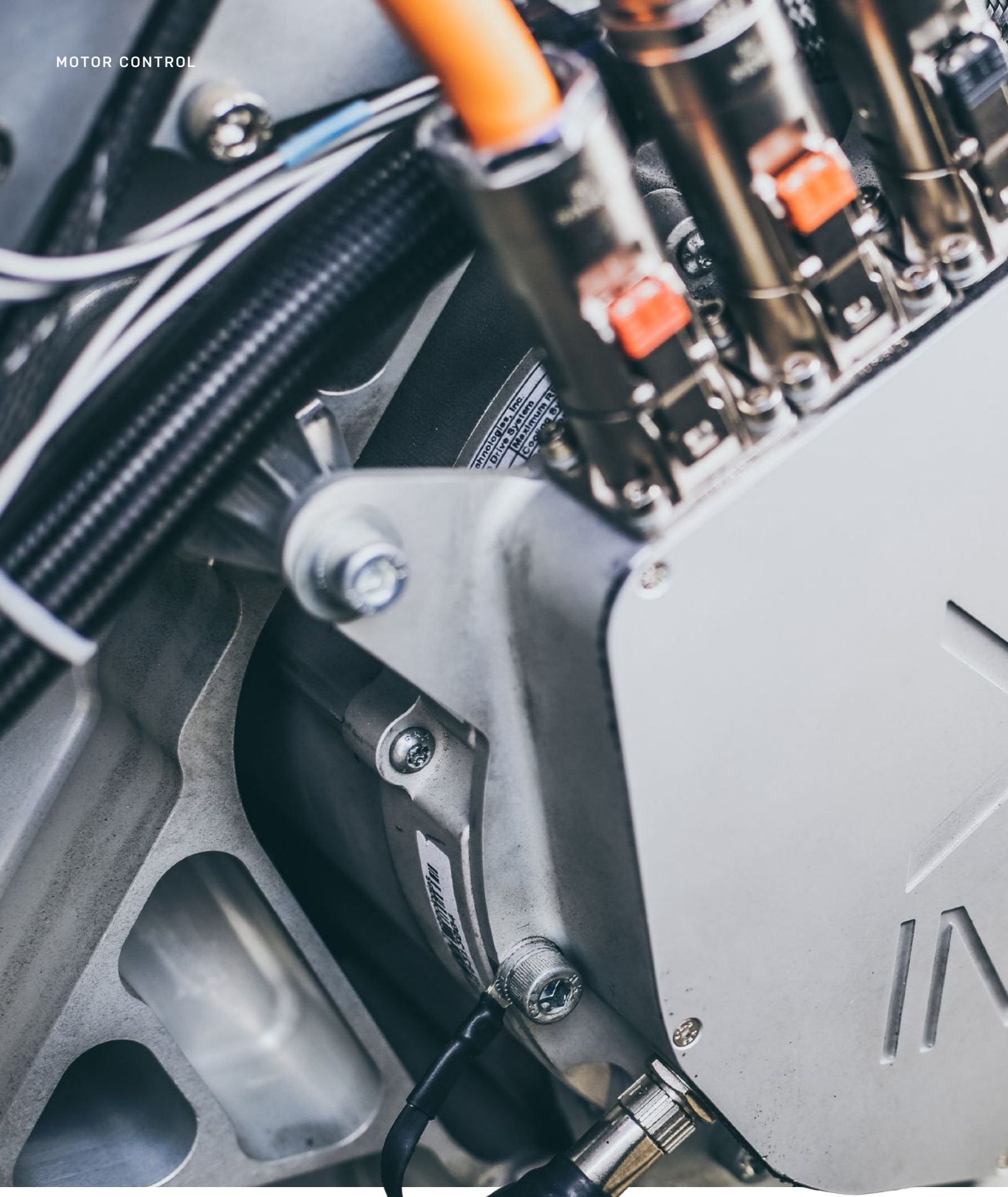
One drives all.

Our **Integrated Drive Module** simplifies the electrification of all kinds of vehicles.

BORGWARNER



No power without control

WITH CONSUMERS DEMANDING EVER-GREATER REFINEMENT FROM EVs, IN ADDITION TO IMPROVED RANGE AND EFFICIENCY, MANUFACTURERS NEED TO ACHIEVE PRECISE CONTROL OVER TRACTION MOTORS

Words: Wayne Ward

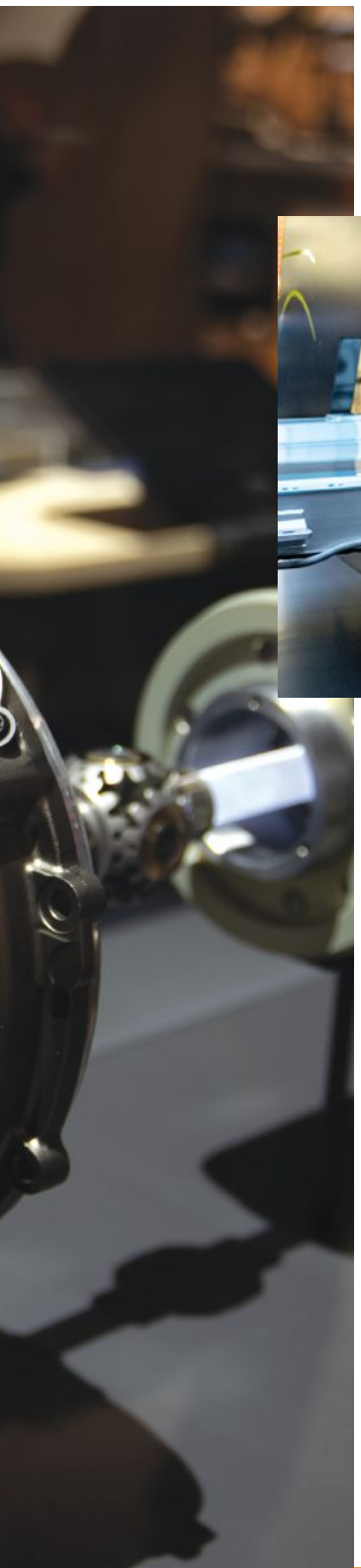
The rise of electric powertrains has happened with a rapidity that few expected, and there is an ever-increasing number of very credible vehicle choices available to drivers looking to buy or lease a new car. In some areas of the world, the number of EVs as a proportion of vehicles sold is very high; in others, that proportion is a mandated minimum that rises to help meet decarbonization targets. For those who can charge at home and whose use case fits the vehicle, an EV can be a sensible financial choice. As battery prices fall and economies of scale improve for many new models, the cost of new electric vehicles continues on a path to price parity with those powered by IC engines. What seems certain is this: EV sales will rise, supported by legislation, and ICE-powered vehicles are in decline. EV makers are trying to produce great vehicles to attract customers. Ever-increasing output and acceleration are gimmicks – everyday

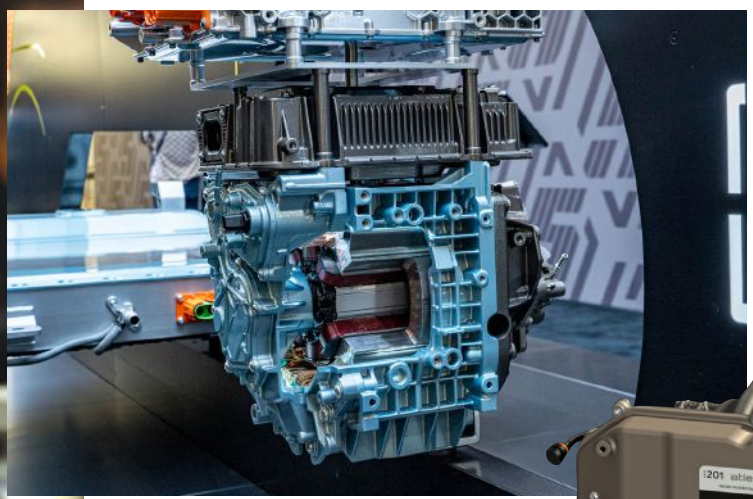
Black boxes

Fuzzy logic, neural networks, genetic algorithms and artificial intelligence are changing the nature of motor control

Control systems that treat the motor system as a 'black box' rather than a mathematical system with known, predictable behavior can control the motor not only to improve the inherent fluctuations in output torque but also to react to external influences and unexpected changes. Although engineers thrive on understanding systems in detail, we are entering an era when we are surrendering control in many areas of life to systems that do not try to understand and model but only to work out a solution to simultaneous changes in multiple parameters. When something unknown comes to act upon an EV drive system temporarily or permanently and causes it to behave unacceptably, such 'black box'-based control systems will act to bring the system back within limits and can do this even when the complexity of the system is well beyond the abilities of conventional control methods.

References 3 and 4 (overleaf) are examples of valuable research into AI methods of motor control.





LEFT, ABOVE & RIGHT: From Lucid's high-power-density permanent magnet machines, to Renault's AC synchronous motor in the new 5, advances in motor control are enabling greater refinement and efficiency

drivers may be seduced by the novelty of such performance but all they actually want is a quiet, efficient car for their daily commute.

Electric powertrains continue to develop to give increased power density in the gravimetric and volumetric senses, and we continue to see gains in powertrain efficiency, despite the fact that electric powertrains are essentially very much more efficient at converting energy than IC engines. Other than at the margins of the speed-versus-load efficiency map, there simply aren't huge gains to be made with a well-engineered electric motor. Likewise, each step of the energy conversion process, whether chemical to electrical, or simply converting a high-speed motor output to a much lower-speed transmission output, is characterized by high efficiency.

There are some obvious efficiency gains to be made by matching electric powertrain performance more closely with real-world driving habits and, hopefully, those efficiency gains will come. However, for the time being, EV drivers enjoy having a surfeit of performance in their vehicles, which is a useful tool to convert ICE drivers to EV fans, if the low cost of running and quiet driving experience has not yet convinced them.

REFINEMENT

There are several important performance, refinement and efficiency metrics that have led the automotive industry to favor the permanent magnet synchronous motor as the primary means of propulsion of electric vehicles. For motors driving two axles, with the secondary axle only turned on as required to meet performance or traction targets, the second (and largely unused) motor is often an induction motor owing to the lower losses associated with this type of motor when not providing driving or braking torque.

During operation, the permanent magnet motor has good dynamic response, good torque-speed characteristics, quiet operation, high power and torque density, and high efficiency. It is also very robust. I have recently been involved in the benchmarking of an EV powertrain and there is a large area in the middle of the operating map where maximum efficiency is >96%.

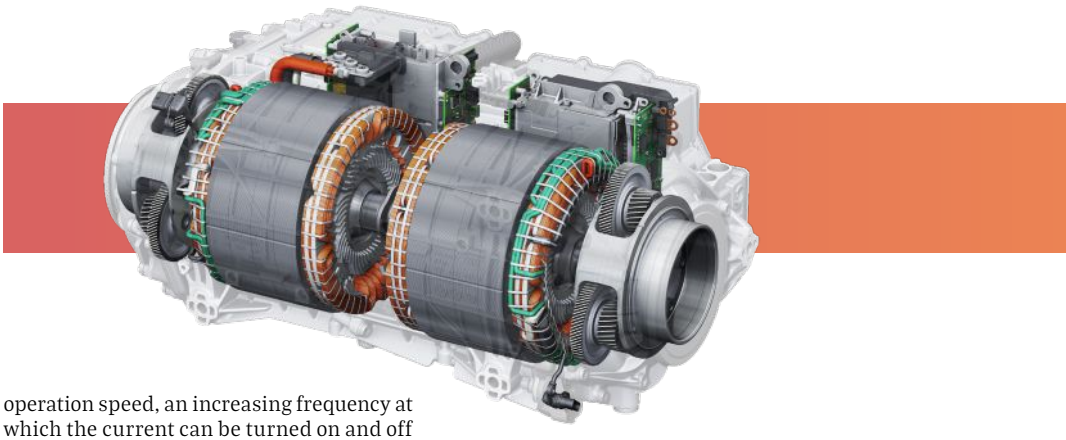
The control of the drive motor is an important aspect of what makes an EV a compelling vehicle to drive, not only in terms of performance and efficiency but also in helping the manufacturer to give the vehicle a sense of refinement and perceived quality. That sense of refinement is, if anything, more important in an electric car than in one powered by an engine. Engines are fundamentally noisier and, in almost all cases, they are the source of a lot of vibration. That engine sound and vibration are able to effectively mask other sources of noise. Vehicle manufacturers have found themselves needing to have an increased focus on NVH once again. Achieving a similar level of customer satisfaction with respect to the NVH characteristics of an electric vehicle requires much more effort than with an ICE vehicle. In an EV, road noise and wind noise are more intrusive, and noise/vibration from the powertrain is similarly very much more apparent. Powertrain-induced noise in EVs can be more noticeable; not only is it heard against a much quieter background but it is not the broad-band spectrum of frequencies that characterize the noise from an IC engine. Our senses are more sensitive to a level of noise with a narrow frequency range.

There are many books on the control of AC electric motors, and specific titles dedicated to the control of permanent magnet motors

as applied to electric vehicles.[1,2] It is certainly beyond the scope of a short article such as this to delve into the more technical aspects of motor control but, for those whose experience is mainly involved with IC engines, there are some reassuring parallels. For an engine, the timing of the injection of the fuel and the start of ignition are important factors concerning efficiency and refinement. In an AC electric motor, the speed and load are controlled by the application of alternating currents. The shape and timing of these currents affects the performance of the motor but also the character of the output and the harmonics of the torque produced.

There are some basic aspects of motor design and practical construction that can cause the motor output to deviate from the ideal steady torque that we desire. In the same way that IC engine torque has strong harmonic content that can excite resonance in the chassis (and the driver), so electric motors are similarly affected.

To provide the smoothest-possible torque output, the control system needs to supply a suitably smooth input of energy in the form of alternating current. The most basic form of alternating current comes from simply switching the current on, holding it and then switching it off. This produces a square wave and, for those of us who perhaps recall our painful experience of harmonic analysis, a square wave is full of very many harmonics and is likely to excite every possible resonance. The ideal current waveform in a highly linear system is something approaching a sine wave, but this has to be produced from a device whose main 'trick' is to turn on and off. However, by turning the flow of current on and off for exactly the correct amount of time and at the correct time, we can closely replicate a sinusoidal current waveform. The speed at which we do this, i.e. the rate at which we turn the flow of current on and off, rises linearly with speed, and within a given sinusoidal cycle, the number of switching events dictates the accuracy with which we can produce the sinusoidal waveform. For a given motor operation speed, an increasing frequency at which the current can be turned on and off results in greater waveform accuracy.



HIGH-SPEED CONTROL

There has been a significant trend toward higher motor speeds to produce the smallest-possible electric machines that can provide the required power output. These might be small, relatively low-torque machines but their torque is multiplied by the transmission ratio that is required to reduce motor output speed to road speed. However, due to their speed, they require higher control system switching frequencies for a given level of waveform accuracy.

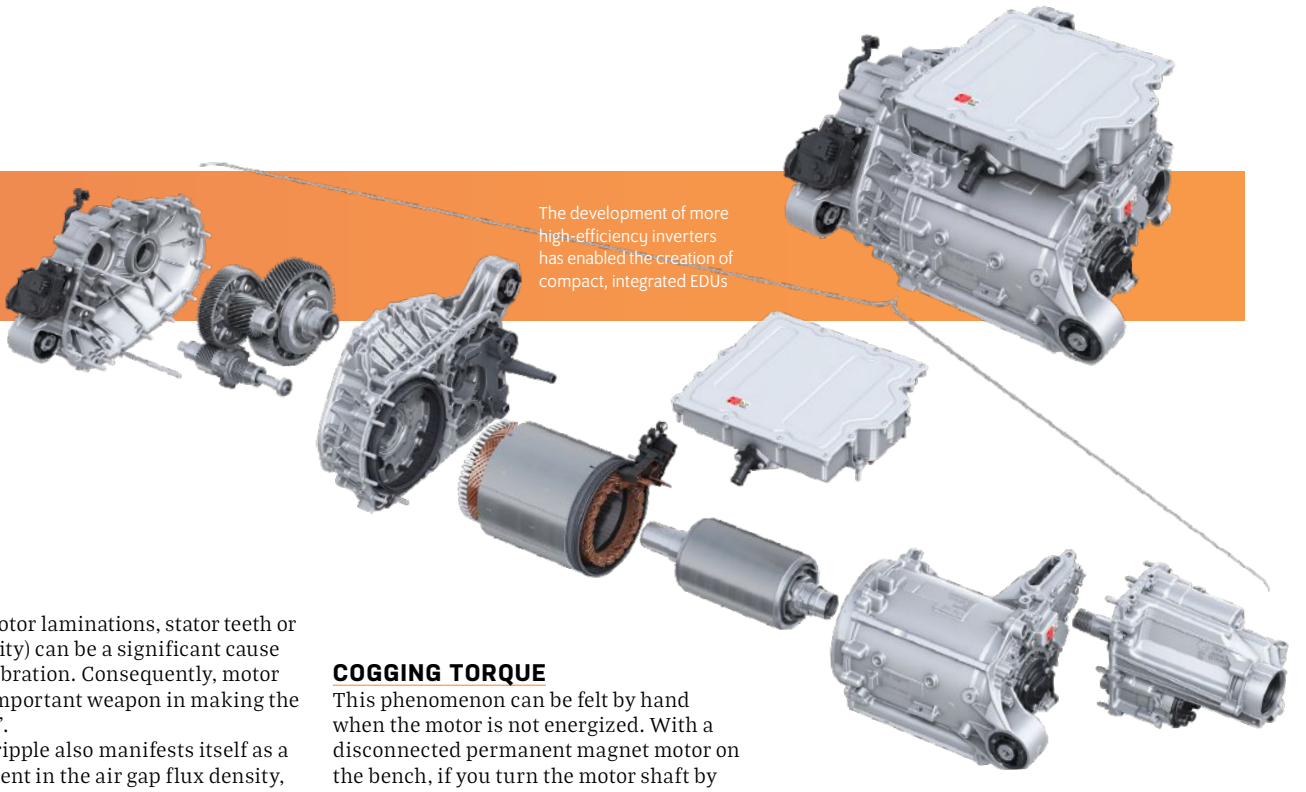
So, we have two factors – namely increasing motor speed and a desire to have more control over the accuracy of the current waveforms – that drive us to use controllers at very high switching frequency.

Imagine a situation where we have such fine control that we not only have the sinusoidal waveform that we want but can also tailor it at will, accurately adding harmonics. Such control over the current waveforms can effectively mitigate unwanted effects on torque output such as ripple and cogging torque.

TORQUE RIPPLE

Compared with an IC engine, the variation of torque over small periods of time (such as that characterized by the time for an engine to complete a full cycle of operation) is very low. However, because the electric motor is so quiet and because efforts are made to reduce wind and road noise to a minimum, this small torque ripple (which might be caused by the fundamental slot and pole count of the motor or by other factors such as magnet distribution, detailed

ABOVE & BELOW: Regardless of motor type, be it a PSM, synchronous machine, axial or radial flux, NVH is a vital consideration and motor control strategies can be used to minimize it



The development of more high-efficiency inverters has enabled the creation of compact, integrated EDUs

design of the rotor laminations, stator teeth or rotor eccentricity) can be a significant cause of noise and vibration. Consequently, motor control is an important weapon in making the motor 'quieter'.

The torque ripple also manifests itself as a ripple component in the air gap flux density, and this excites vibration of the stator teeth, which results in noise and vibration. This noise is amplified because it causes resonance with the natural structural modes of the machine owing to geometry, mounting, etc. Electromagnetic noise has strong harmonics and can sound unpleasant to the vehicle occupants compared with broad-band noises. By careful control of the shape of the alternating currents and their harmonics, we can reduce torque ripple.

In a basic way, we can predict the behavior of the motor from its basic geometry and parameters, and the current waveforms, controlling it by supplying what we believe is a suitable current waveform. The simplicity/complexity of the waveform will have implications for performance and the nature of the torque output.

COGGING TORQUE

This phenomenon can be felt by hand when the motor is not energized. With a disconnected permanent magnet motor on the bench, if you turn the motor shaft by hand, a periodic pulsating torque is felt. On the first propulsion motor that I worked on in the late 1990s, this cogging torque was very significant, to the point that it was a genuine struggle to turn the motor shaft; it required a very tight grip and a strong arm. Just 15 years later, the effort to turn a much smaller permanent magnet AC motor (of a similar output) required so little effort to overcome the cogging torque that it could be done with a very light grip.

It can be shown that the least common multiple of the slot and pole numbers of the motor determines the cogging period (the angle between cogging torque maxima). Again, through changes to motor control, the predictable torque oscillations inherent in a given design of permanent magnet machine can be mitigated to a large extent.

SUMMARY

Effective control over EV propulsion motors will help to improve not only the performance and efficiency of our powertrains but also the more qualitative aspects such as noise and vibration. The perceived quality of electric vehicles depends on the ability of engineers to control NVH because these are pervasive factors in a vehicle that is much quieter than its ICE counterpart.

In the future, control systems will treat the system as a 'black box', measure the quality of the torque output and make changes to the shape of the current waveforms to reduce effects such as torque ripple, even in non-linear systems like PM motors where effects such as hysteresis, saturation and iron losses complicate matters.

About the author

Wayne Ward is a powertrain engineer with over two decades of experience across a diverse range of disciplines. He has had considerable involvement in top-level motorsport with the likes of Cosworth, Honda Racing Development and Mercedes AMG Performance Powertrains, working on ICE and hybrid/electric powertrains. He has also been active in the mainstream automotive sphere as a consultant engineer on electrification and combustion projects and across other industries including nuclear power

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The next frontier

GALLIUM NITRIDE (GaN) INVERTERS PROMISE HUGE IMPROVEMENTS IN SWITCHING SPEED AND EFFICIENCY. COULD THEY BE THE NEXT BIG THING IN AUTOMOTIVE POWER ELECTRONICS?

Words: Chris Pickering

STATOR (s3x51n)
s/n: 3941501
MT-450919
Op.T 10-150
Winding F: 0.99
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Trans.Gear 1:3.25
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Teeth: 40
Prototype Phase

The importance of silicon carbide (SiC) inverters in the rise of electric vehicles is hard to overstate. SiC technology has played a key role in enabling 800V architectures and the improved charging speeds these offer. Faster switching speeds, higher current capacities and a wider temperature range than traditional silicon semiconductors have also helped to send SiC inverters to the top of every manufacturer's wish list.

But what if there were something better? Something that could take the advantages of SiC devices and push them further?

That's precisely what gallium nitride (GaN) semiconductors have the potential to do. Compared with SiC, they promise even faster switching speeds, smaller and lighter devices, and lower conduction losses. In the long run, they could even prove cheaper.

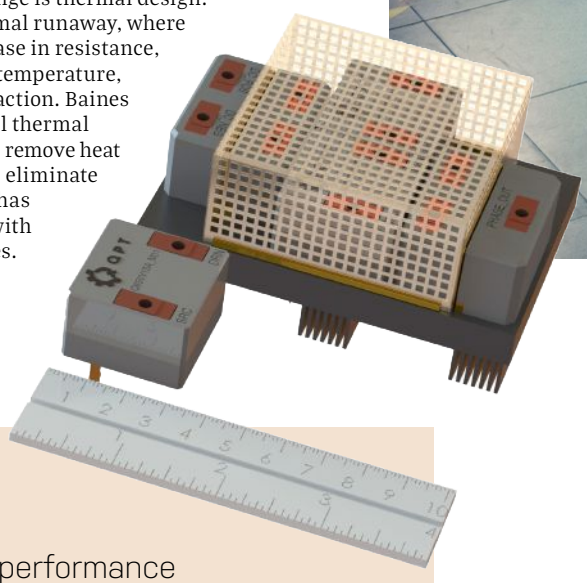
Predictably, there's a catch. Although GaN's theoretical benefits have already been realized in lower-power devices such as cell phone chargers and laptop power supplies, the technology currently struggles with the higher voltages and power levels required for automotive traction inverters.

"GaN is simply a much better semiconductor," says Rupert Baines, CEO of UK-based startup QPT. "It has far lower losses, it's easier to charge and discharge, it doesn't have a body diode, so there are no recovery losses. Instead of using conduction, it's based on an electron gas, so the electrons just float through the device with no resistance, which generates a fraction of the heat. Physicists have known all this for 40 years; they just couldn't make GaN transistors in any sort of volume."

One of the challenges is that GaN is a lot more fragile than the more common semiconductor materials. There have been improvements in substrate technology and device topology within the transistors themselves, but GaN is still marginal on voltage capability for automotive applications, and clever system-level design is needed to make inverters work reliably.

"In order to switch very quickly without failure, the delivery of energy into the transistor has to be governed very carefully," notes Baines. "You also need to make sure that if there's a short circuit for any reason, it remains safe."

The second challenge is thermal design. GaN is prone to thermal runaway, where heat causes an increase in resistance, which increases the temperature, leading to a chain reaction. Baines says that with careful thermal design it's possible to remove heat effectively enough to eliminate this danger, as QPT has succeeded in doing with its mid-power devices.



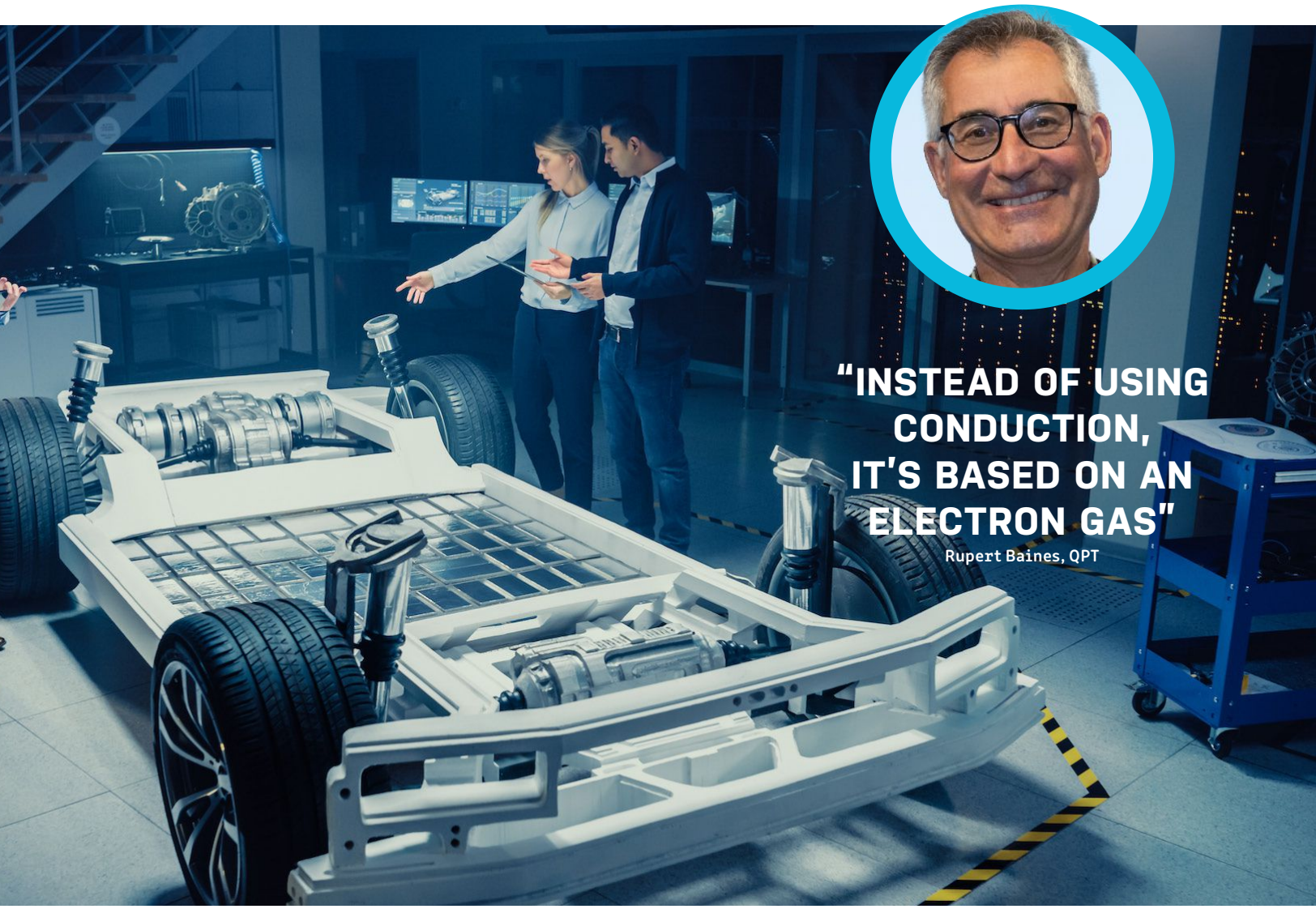
BELOW: A variable frequency drive (VFD) developed using GaN semiconductors by QPT

All quiet

GaN brings other advantages beyond pure performance

The speed of a GaN inverter allows it to drive the motor with a smooth sine wave, rather than the abrupt pulse-width modulated square wave generated by a traditional device.

"With a PWM signal, the inverter slams the motor with an electric field. That causes vibration, acoustic noise and, ultimately, damage to the bearings. It also generates horrible harmonics that lead to lots of electrical noise," comments QPT's Rupert Baines. "If all the noise is captured inside that box and screened, and the only thing that goes out is a clean sine wave, you don't have any EMI to deal with externally. It's what a motor dreams of seeing. It also means you could potentially ditch kilos of NVH material currently used for sound deadening."



"INSTEAD OF USING CONDUCTION, IT'S BASED ON AN ELECTRON GAS"

Rupert Baines, QPT

"We can move into the 10kW class today because we've solved those issues," he says. "The reason we can't yet move into the 100kW range is mainly because of the voltage limit. Cars are rapidly moving from 400V up to 800V. We could produce a 400V design but nobody really wants those anymore. Once GaN transistors are available that will work at that sort of voltage, we will see GaN traction inverters in EVs."

High-voltage GaN transistors have been produced in the past. Experimental devices on a silicon carbide substrate have been proved to operate at over 3,000V, but most experts agree that the business case for GaN devices relies on the use of a more affordable silicon base.

Inspirit Ventures CEO Geoff Haynes is a semiconductor industry stalwart with more than 50 years' experience. He was the co-founder of GaN Systems and worked on the 3,000V GaN transistors developed by Taransys.

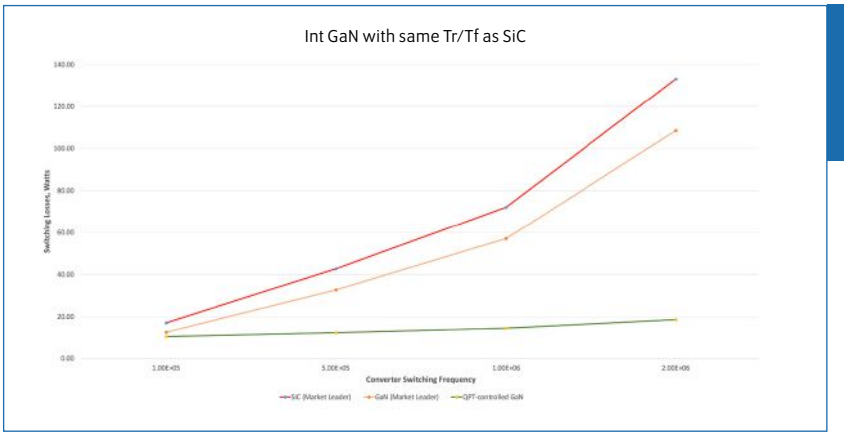
"The challenge with using a silicon substrate is that it's a conductor, and the channel that carries the current in the device breaks down to that substrate at typically 1,100 or 1,200V," he explains. "By the time you've put some safety margin on top of that, it limits the present technology to around 650V. There is a lot of work going on among the semiconductor manufacturers to increase the depth of the AlGaN insulator, so the channel is farther away from that breakdown surface of the substrate. As soon as we can get GaN devices up to a safe operating range of 1,200V, we'll start to see them in automotive."

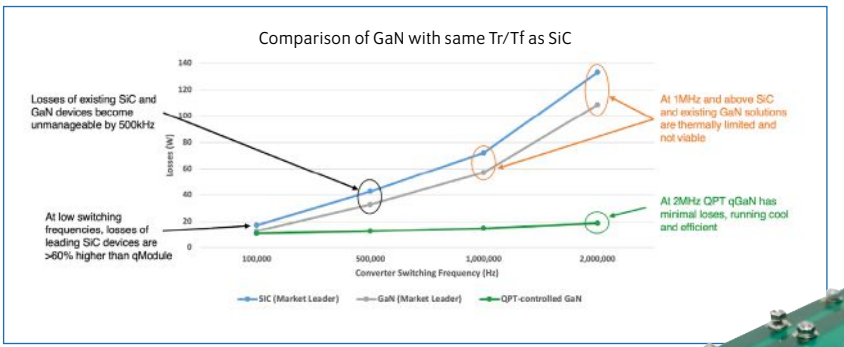
FAST SWITCHING

The key to the advantages of GaN devices is the speed at which they can switch. No transistor switches on and off instantaneously. Instead, there's a brief transition period as the power level ramps up (or down), during which time its power losses increase dramatically. This period lasts for around 30 to 60 nanoseconds on a traditional silicon IGBT. SiC slashes that to somewhere between six and 15 nanoseconds, but the fastest GaN devices can get down to around one nanosecond.

These periods of time might seem infinitesimally small, but when the device is switching 10,000 to 20,000 times a second, they soon add up. As Haynes notes, "A transistor that switches in one-tenth of the time wastes one-tenth of the energy."

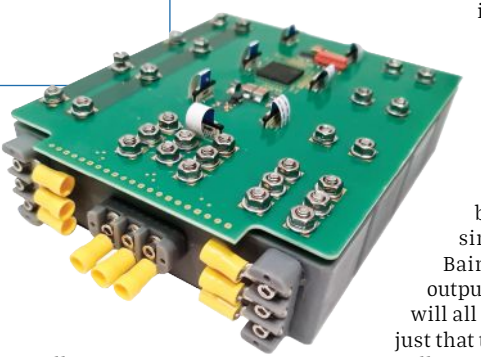
Switching faster wastes less heat, which means that the devices themselves can be smaller and lighter. And as Baines points out, it can also set off a virtuous circle throughout the vehicle. "On a WLTP cycle you might be getting 85% efficiency, between the losses in the motor and the losses in the inverter. Going to the best SiC devices, you might get 90%. That 5% increase means you might be able to run a 5% smaller battery for the same range. That improvement has also reduced your heat rejection by a third, which means a third less




Comparison of GaN with same Tr/Tf as SiC
Losses of existing SiC and GaN devices become unmanageable by 500kHz
At low switching frequencies, losses of leading SiC devices are >60% higher than qModule
At 1MHz and above SiC and existing GaN solutions are thermally limited and not viable
At 2MHz QPT qGaN has minimal loses, running cool and efficient
Losses (W)
Converter Switching Frequency (Hz)
SiC (Market Leader)
GaN (Market Leader)
QPT-controlled GaN

LEFT: A comparison between the losses of SiC and GaN devices

BELOW: The internals of QPT's VFD



"THE GAN TRANSISTOR IS ACTUALLY A VERY SIMPLE STRUCTURE"

Geoff Haynes, Inspirit Ventures

heat sink and a smaller cooling system.

"But with GaN, the increase might be from 90-95%, so you're not reducing your waste heat by one-third, you're reducing it by two-thirds [compared with silicon]. What could that mean? It has been suggested that we're not far away from the point where lower-powered city cars could replace liquid cooling with air cooling, like Volkswagen did with the original Beetle. At that point, you're not wasting energy in the cooling, you're making everything smaller, you're making everything lighter and you're making everything simpler."

PACKAGING OPTIONS

The compact size of GaN inverters could make it easier to package the drive system inside the motor itself, aiding integration. It could even assist with the move toward greater recyclability. "People are starting to ask, 'Can we use aluminum windings in the motors, and make those flat so they're easier to wind?'," Haynes notes. "By moving to aluminum, you have the advantage that you could melt everything down at the end of life. And if you can make them square, you might actually be able to mount the transistors directly onto those as heat sinks. So there's a tremendous amount of work going on into ways to simplify, reduce the heat production and integrate the whole of the motor and its drive system. Switching to GaN makes the components so much smaller – tiny little coils rather than large inductors – which could help to enable this change."

There's no doubt that GaN technology would cause the Tier 1 and Tier 2 suppliers some headaches. The mechanical, thermal and electrical design within the inverter would have to be revised to support the new technology – in contrast to SiC, which is pretty much a drop-in substitute for silicon. For vehicle manufacturers the benefits would be much simpler to unlock, says Baines: "The inputs, the outputs and the control signals will all be much the same; it's just that the inverter will get a lot smaller and the cooling system requirements will go down."

Delivering these benefits is a work in progress, but Haynes and Baines both believe it should be realistic within the next couple of years. Perhaps what's most surprising for a new technology backed by such ambitious claims is that they also believe that it could be cheaper than SiC.

"High-power GaN transistors are more expensive than SiC at the moment, but that's largely because the market isn't there for them yet," says Haynes. "The GaN transistor is actually a very simple structure; there are far more processing steps involved in SiC. If the industry can tip the supply and demand for GaN, it will knock SiC out of the park."

The key to all of this is context. Haynes emphasizes that it isn't a question of outright superiority, but rather picking the best material for the requirements, with silicon and SiC still having major roles to play in different applications. For automotive traction inverters, however, the case for GaN appears compelling, providing the challenges around voltage and power capability can be solved.

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JOULES OF WISDOM

TEST HOUSES MUST BE SAVVY WITH THEIR ENERGY MANAGEMENT PRACTICES TO MEET THE DEMANDS OF POWERTRAIN DEVELOPMENT

Words: Gemma Hatton

One of the biggest headaches of running a test facility is handling the constantly fluctuating power demand of multiple dynos. Each dynamometer needs energy to power the unit under test and the supporting systems during steady-state and transient tests, which leads to widely varying power requirements. Balancing this with the regular power needs of the building is pushing test houses to adopt new strategies for sourcing, distributing and managing additional power.

"The single biggest challenge when developing a new facility is getting enough power on-site in the first place," highlights Rob Oliver, managing director at the Institute of Advanced Automotive Propulsion Systems (IAAPS), which is equipped with a range of equipment that has differing power demands. "This is exactly why we located IAAPS on the [UK's] Bath and Bristol Science Park, which is close to the east/west grid infrastructure. This enables us to have our own dedicated 13MW incoming power supply, which is otherwise restricted in many other areas of the country."

Determining how much input power a facility needs is not a straightforward calculation. Says Jonathan Peters, EV chief engineer at Intertek, "Test facilities must evolve over time to meet the needs of industry. As such, the facility must be designed to be flexible right from the start. You have to take a bird's-eye view of the building and figure out the maximum number of test cells and facilities that can be accommodated within the

available space either now or in the future. Then you need to calculate a reasonable worst-case scenario on energy demand."

Naturally, the energy demand chops and changes based on the type of evaluation and the project at hand. For instance, high-performance ICE analysis can generate over 500kW of electrical energy, and battery pack testing may periodically require or produce a similar amount of power.

WASTE NOT, WANT NOT

Managing the energy waste produced during testing is another important factor to consider – and addressing it requires power. Energy recovery strategies should be employed where possible. Oliver notes, "For dyno testing ICEs, roughly a third of the power comes out the exhaust, another third is rejected into the air or cooling system as heat, and the final third comes out at the flywheel."

This means two-thirds of the waste must be handled, which demands power from the building. However, heat recovery systems can help offset this power demand. Meanwhile, the power generated by the flywheel is absorbed by the dynamometer motors, converted into electricity and fed back into the building's main power supply.

Analysis of e-motors on dynos is similar, but the energy generated can either be fed back into the building or reused to drive the e-motor dyno itself, Oliver explains, "In this case, the only power required from the mains supply is to top up any losses within the system, which is typically around tens of kilowatts due to the high efficiencies of today's motors.

"If we're testing ICEs, we are effectively turning gasoline or diesel into electricity and putting that power back into the building. Whereas with e-motor testing we're taking power from the building, but only a small amount to compensate for the losses within the motor and power electronics."

Scrutinizing an e-motor on a dyno usually involves testing against another electrical machine – the dyno itself. As both machines are typically highly efficient, power recirculates, resulting in relatively low and steady system power under constant speed conditions. However, during acceleration the transient demand needed to speed up the rotating components can require a considerable surge in electrical energy. This must be factored in when calculating the worst-case power demand.

Says Peters, "That might happen in one test cell, but you also need to consider the chances of those transient events occurring in multiple test cells at the same time. You have to make calculated decisions about how that will affect the energy and power demand of the building."

> **"IT'S THE MASSIVE POWER DRAWS THAT ARE THE BIGGEST CHALLENGE"**
> **Emma Deutsch, Nissan Technical Centre Europe**

Peters notes that it's not just the dynos consuming energy but also the ancillary systems that support them: "Each test cell often requires conditioned fluid and air, which must be sized for parallel operation. These systems create a baseline energy load on the building, which is easy to overlook but can make up a significant portion of the overall energy budget."

POWER TO SHARE

After securing the right power supply, the next challenge is efficiently distributing it throughout the site. Typically, electricity from the grid passes through a local substation before being routed into the test facility via a site distributor.

"We took the approach of using a high-current three-phase bus-bar system," explains Oliver. "So instead of hard-wiring each of the cells or dynos back to the distribution board, we run a high-current ring around the building, which we plug all the equipment into. This serves two purposes. First, it saves on extensive high-current cabling, which is both heavy and expensive. It also gives us flexibility because we can easily change what equipment we 'plug in' to this ring."

For its most complex rigs, such as the five-machine powertrain facilities, the

The power needed to operate a multipurpose facility like IAAPS fluctuates continuously based on the rigs in use and the types of analyses being performed

LEFT: Electrified vehicle development has substantially amplified the power draws of facilities

BELOW: Unico's new Quantum Drive Platform for battery validation enables the recirculation of energy from various machines

500kW

THE AMOUNT OF ELECTRICAL ENERGY THAT CAN BE PRODUCED DURING HIGH-PERFORMANCE ICE TESTING

Flow control

Electrification evolution

EVs have not only increased facilities' power demands but also changed the electrical infrastructure necessary to accurately assess the powertrains. "With conventional engine dynos, the main transformer has an earth point that all the components (and subsystems) within the test cell can be connected to, which grounds the system," says Chris Hutt, vice president of Europe, Unico.

When it comes to emulating electrified vehicles on dynamometers, an isolation transformer is essential. It provides galvanic isolation – separating sections of the electrical system to prevent unwanted current flow – ensuring the test environment truly replicates that of the vehicle.

Hutt explains that in an EV test resource, the entire system is not directly connected to the ground, which is known as 'floating'. This means that the system's potential to ground can shift, especially when power levels change, creating something called common mode voltage. Anything that is both connected to the equipment being tested and directly grounded could be affected by this shifting voltage. To make the system more stable, a device called a common mode filter (CMF) is used between the power source and the equipment being tested. The CMF is connected to the ground on one side, but the rest of the system, including the kit on test, is still floating.

To understand common mode voltage – the voltage difference between a power source and the neutral point of a load in inverters – Hutt recommends thinking of it like a sailing boat. The height from the deck to the top of the mast stays constant and represents the differential voltage. In contrast, the height from the top of the mast to the sea floor fluctuates with the waves, symbolizing common mode voltage. If common mode voltage isn't accounted for in the design of the installation, it can damage the insulation of internal and external components and cables. According to Hutt, conventional isolation transformers are effective in providing galvanic isolation but are increasingly large and expensive with thermal losses. Thus, Unico is developing resonant converters instead.

"These replace the isolation transformers and do two things," he explains. "They provide complete galvanic isolation and allow you to step up the voltage, while being four times more efficient than a typical transformer and a fraction of the size. They're also much more flexible because you can hang multiple resonant converters off the active front end, which means you can have multiple test cells off one common DC bus, with each one galvanically isolated from the other."

This technique has saved Unico's test facility clients millions by enabling them to recover energy from one test cell to the next, thereby cutting conversion losses. Furthermore, it has done away with the need to install a new transformer or upgrade existing power infrastructure.

LEFT: Versatile rigs are frugal because they enable several tests to be run simultaneously while also making full use of the space

BELOW: Nissan continues to explore alternative energy supply options for its European tech hub

> **"THE FACILITY MUST BE DESIGNED TO BE FLEXIBLE RIGHT FROM THE START"**
>
> **Jonathan Peters, Intertek**

IAAPS uses a common DC bus setup to reduce incoming AC power. Power from the building flows through an active front-end drive, which acts as a controllable rectifier, converting mains AC to DC for use on a DC bus. Each dynamometer is then connected to this DC bus through a DC to AC variable-frequency converter, which supplies AC to each dyno.

AMP UP EFFICIENCY

The surge in electric vehicle development has brought with it high-power chargers – pushing facilities closer to their overall power limits. Eight 300kW chargers with all the latest safety technology were recently installed at the Nissan Technical Centre Europe (NTCE). To accommodate that, Nissan had to upgrade its charging infrastructure and devise strategies to minimize energy consumption while maximizing test efficiency.

Emma Deutsch, director of customer-oriented engineering, test operations and DP office, Nissan Technical Centre Europe, explains, "We've done calculations to understand the power requirements and how we manage those alongside all our other facilities. It's the massive power draws that are the biggest challenge."

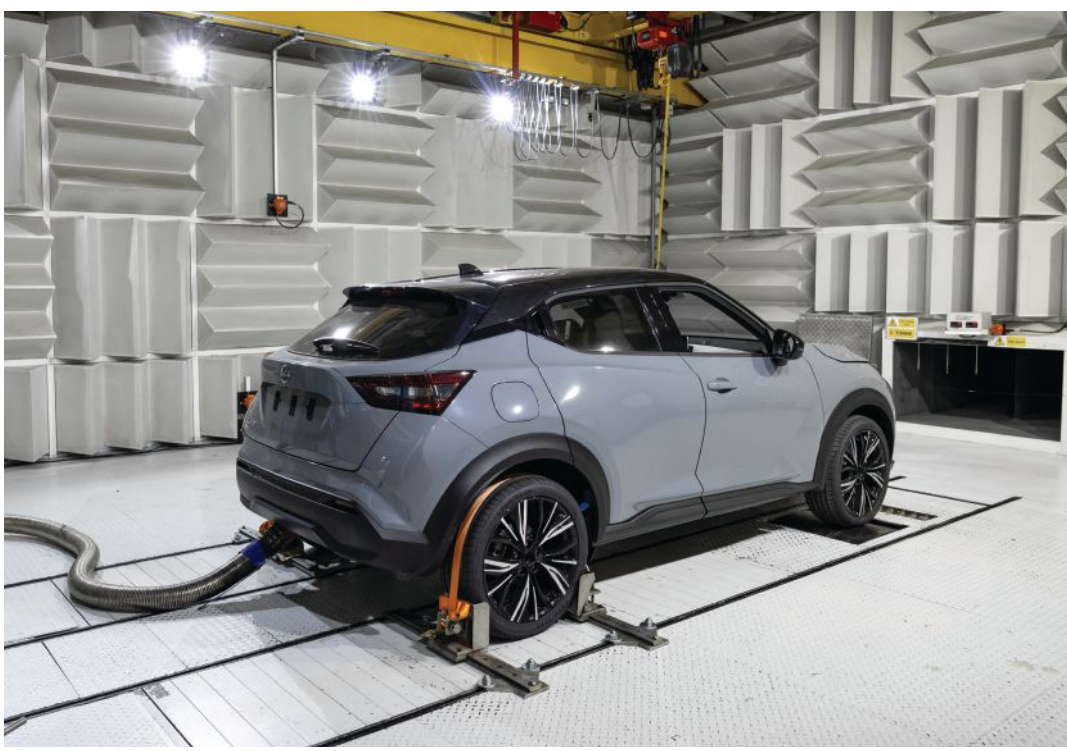
If test centers are limited by their input power from the grid, there are alternatives that allow additional power to be generated or stored on-site. For example, solar panels and wind turbines can be installed, and stationary energy storage systems, which are essentially large batteries, can provide extra energy during peak transient loads.

"We are looking at all sorts of ways of bringing additional power on-site, whether that be solar or battery backup options," reveals Deutsch. "We're currently working on a lot of V2X projects, which involve transferring electricity between EVs and the facility. However, we're facing the challenge of figuring out where all these new systems will fit. Having been at this site [NTCE] for 35 years, we need to manage our remaining space very carefully."

Another approach to managing the growing power demand is to refine the efficiency of the on-site power use, which means being savvy with test scheduling. "We try to combine the types of research we're doing. If one cell is generating and another cell is absorbing then we try to schedule those to run at the same time so we're pulling less power from the grid," says Oliver.

To allow several tasks to be ticked off the to-do list at once, multi-use rigs are favorable. For obvious reasons, this is far more effective than performing analyses separately. "If we're spending millions on a new rig then it has to be capable of doing up to six tests," notes Deutsch. "We have four-post rigs within our climatic chambers, but there are technological limits to consider. For example, we couldn't add humidity into the chamber because it would affect the components of the rig, necessitating costly upgrades. It's a balance between maximizing the multi-use aspect without astronomical costs."

Regardless of the power source or amount, facilities need full visibility into how that power is distributed throughout their buildings. "Having that system-level view of all the power demands within a building and optimizing those to manage overall energy efficiency is essential. Particularly as the demand for EV testing – and the high-power requirements that come with that – will continue to increase," concludes Intertek's Peters.



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SCAN ME

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LEFT: The concentration of some raw materials for batteries, such as lithium, in certain geographic areas presents supply chain challenges

UNBROKEN CHAIN

THE GLOBAL DISTRIBUTION OF THE BATTERY SUPPLY CHAIN, AND THE POTENTIAL FOR ITS DISRUPTION, ARE KEY CONSIDERATIONS FOR AUTOMOTIVE MANUFACTURERS

Words: Frank Millard

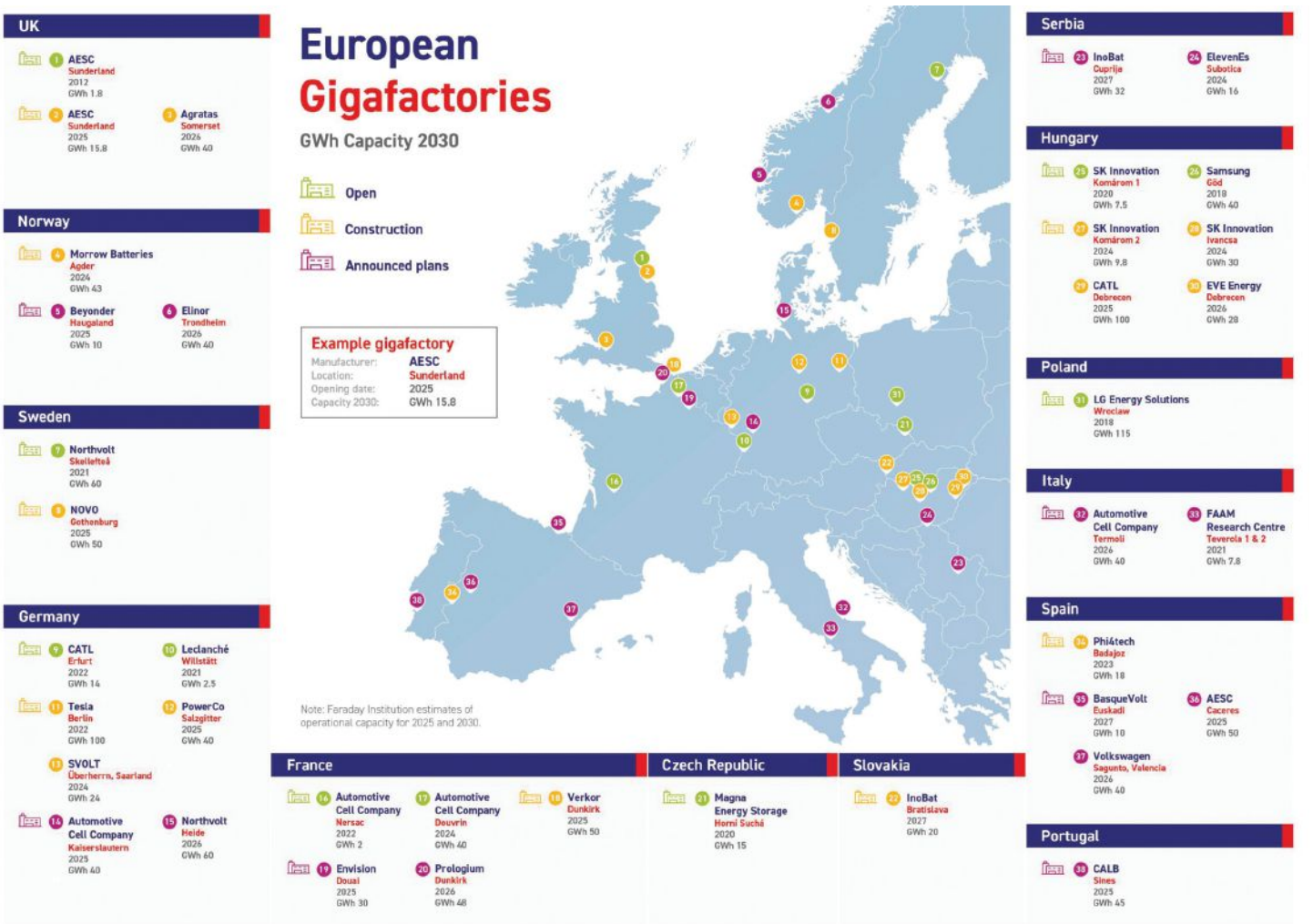
Governments around the world seem to be moving forward with net zero policies with fingers crossed that new battery chemistries, innovative technology and societal adaptation will make their aspirations achievable. However, even with all those ducks in a row, providing the working parts and materials for those batteries on time can be tricky.

A leap in demand for battery electric vehicles is expected and essential to meet national and international targets relating to the replacement of ICE vehicles. However, intention is not always matched by realization. One reason for this is commercial: is the public preference for pure EVs over hybrids and gasoline-driven vehicles sufficient to drive enough sales to meet the targets? The other is the ability of manufacturers to build cars, and battery manufacturers to supply the means by which they are powered. Solving the second issue requires building enough battery gigafactories in convenient locations to shorten supply chains and provide them with sufficient raw materials, the delivery of which needs to be consistent and continual.

Although manufacturing costs have come down as commodity prices have receded from their peaks, the battery sector is now facing reduced demand, oversupply and a scaling back of consumer incentives. Even if these challenges are temporary, they show that battery and EV manufacturing are vulnerable to fluctuating external factors.

Several western gigafactory and battery-related projects are facing delays and cancellations due to weakened demand. "In June, SVOLT cancelled its plans to construct a cell project in Lauchhammer, Germany," reveals Stephen Gifford, a senior economist at the Faraday Institute (a UK-based independent battery research institute). "The

LEFT: Iron ore is the most prevalent raw material globally


European Gigafactories
GWh Capacity 2030
Open
Construction
Announced plans
Example gigafactory
Manufacturer: AESC
Location: Sunderland
Opening date: 2025
Capacity 2030: GWh 15.8
Note: Faraday Institution estimates of operational capacity for 2025 and 2030.
UK
1 AESC Sunderland 2012 GWh 1.8
2 AESC Sunderland 2025 GWh 15.8
3 Agratas Somerset 2026 GWh 40
Norway
4 Morrow Batteries Agder 2024 GWh 43
5 Beyonder Haugaland 2025 GWh 10
6 Elinor Trondheim 2026 GWh 40
Sweden
7 Northvolt Skellefteå 2021 GWh 60
8 NOVO Gothenburg 2025 GWh 50
Germany
9 CATL Erfurt 2022 GWh 14
10 Leclanché Willstätt 2021 GWh 2.5
11 Tesla Berlin 2022 GWh 100
12 PowerCo Salzgitter 2025 GWh 40
13 SVOLT Überherrn, Saarland 2024 GWh 24
14 Automotive Cell Company Kaiserslautern 2025 GWh 40
15 Northvolt Heide 2026 GWh 60
France
16 Automotive Cell Company Nersac 2022 GWh 2
17 Automotive Cell Company Douvrin 2024 GWh 40
18 Verkor Dunkirk 2025 GWh 50
19 Envision Douai 2025 GWh 30
20 Prologium Dunkirk 2026 GWh 48
Czech Republic
21 Magna Energy Storage Horní Suché 2020 GWh 15
Slovakia
22 InoBat Bratislava 2027 GWh 20
Serbia
23 InoBat Đuprija 2027 GWh 32
24 ElevenEs Subotica 2024 GWh 16
Hungary
25 SK Innovation Komárom 1 2020 GWh 7.5
26 Samsung Göd 2018 GWh 40
27 SK Innovation Komárom 2 2024 GWh 9.8
28 SK Innovation Ivancsa 2024 GWh 30
29 CATL Debrecen 2025 GWh 100
30 EVE Energy Debrecen 2026 GWh 28
Poland
31 LG Energy Solutions Wroclaw 2018 GWh 115
Italy
32 Automotive Cell Company Termoli 2026 GWh 40
33 FAAM Research Centre Teverola 1 & 2 2021 GWh 7.8
Spain
34 Phi4tech Badajoz 2023 GWh 18
35 BasqueVolt Euskadi 2027 GWh 10
36 AESC Caceres 2025 GWh 50
37 Volkswagen Sagunto, Valencia 2026 GWh 40
Portugal
38 CALB Sines 2025 GWh 45

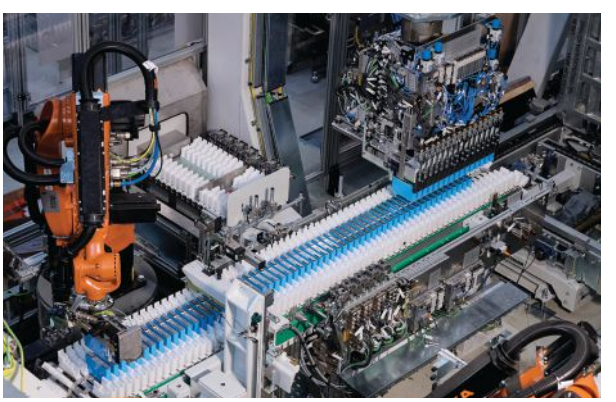
company cited low planning certainty and a weak demand outlook as the main factors influencing the decision. Most notably, Northvolt recently disclosed that it has moved its focus away from cathode production, opting instead to only focus on its cell production capabilities."

Although the demand for critical minerals is expected to be met globally in the near term, the supply chain is highly concentrated in a few countries such as China and its satellites, through which much global processing capacity for lithium and cobalt passes. Given the growing geopolitical tensions, this is not ideal.

Mass global demand, geographically piecemeal availability and national/commercial requirements are creating winners and losers. "The intense competition for key mineral resources risks creating bottlenecks and risks, particularly for those without secure long-term offtake agreements," says Gifford. For example, gigafactories with supply agreements in place can put latecomers at a disadvantage.

AVAILABILITY OF RAW MATERIALS

According to the US Geological Survey's Mineral Commodity Survey 2024, of all the minerals used in EV batteries, iron ore reserves were the most plentiful in 2024, with approximately 800 billion metric tons available globally. Lithium, on the other hand, had much lower global reserves – around 303.5 million metric tons according to S&P Global Commodities insights. This, as demand for lithium is predicted to grow fivefold in 2030, increasing to a 14-fold rise in 2040 compared with 2020. According to Evan Hartley, a senior analyst at Benchmark Mineral Intelligence, although raw material supply and demand are generally looking balanced across the rest of the decade, recent low-price environments have led to mine closures. Combined with supply interruptions, he believes this means that "there is the potential for lithium to enter a deficit toward the latter half of the decade."



Prof. Simon Michaux, associate professor of geometallurgy at the Geological Survey of Finland, says that sourcing enough metal to produce EVs under the current plan is not going to work: "All chemistries I've looked at require copper, graphite and nickel. Most need cobalt. Even if we were to use something other than lithium-ion chemistry, there would be serious material shortfalls going forward." In his opinion, the market will shift to a new technology that doesn't face these constraints."

GEOPOLITICS

The patchwork nature of mineral reserves globally has geopolitical implications. For example, cobalt supply is

LEFT: The location of current and proposed battery gigafactories in Europe by 2030

dominated by the Democratic Republic of the Congo, which in 2023 held more than half of the 11,000,000 metric tons of global reserves, according to Statista. Second was Australia, with 1,700,000 metric tons. In the same year, Indonesia had the most nickel, at 1,800,000 metric tons. Lithium reserves in Chile were the largest in 2023, but Australia (in second place) led in actual production.

Prof. Gavin Harper at the University of Birmingham's School of Metallurgy and Materials believes that having minerals in the ground is not enough: "China has secured a commanding competitive edge in rolling out gigafactory capacity at scale, which completely overwhelms the market relative to capacity in the West."

This, he says, is because the Chinese economy works in a fundamentally different way from Western economies, making competition difficult. "There are serious risks that if we completely cede battery production to China, we will lose all the other parts of the automotive supply chain," he warns.

Innovative technology undoubtedly has a role to play but it must be scaled at pace to enable the West to stay in the game, Harper cautions. Not only did China have the foresight to invest in securing supplies of critical materials and building out the capacity, but it also holds a monopoly on the supply of the rare earths.

Andreas Breiter, a partner at McKinsey & Company, forecasts more localized production along the value chain: raw materials, refining, component production, cell manufacturing and recycling.

"The USA has a requirement for production in certain geographies to take full advantage of regulatory support," he says.

Circular thinking

What impact will recycling have on the availability of battery materials?

EV battery recycling is currently small-scale but is expected to grow dramatically in the 2030s as increasing numbers of EV batteries reach the end of their automotive life.

China is ahead in the recycling race as it is in most things associated with EVs. In 2023, global recycling capacity was 300GWh/year, according to the International Energy Agency (IEA), of which 80% was in China. The USA and Europe's share amounted to just 2% each.

IEA estimates that by the year 2040, recycling could supply up to 51% of EU cobalt demand and 42% of nickel.

If all the announced recycling projects are fully realized on time, global recycling capacity could exceed 1,500GWh in 2030, of which 70% will be in China, and about 10% each in Europe and the USA.

Evan Hartley at Benchmark believes that establishing a robust domestic recycling industry is crucial to reduce reliance on imported raw materials. Key priorities include advancing recycling technologies, developing direct recycling methods and improving recovery rates. Standardizing and simplifying battery designs will potentially enhance efficiency and lower costs across the supply chain, he says.

According to the University of Birmingham's Gavin Harper, the key is to keep batteries in a high value state for as long as possible by separating materials cleanly rather than shredding and mixing them together at an early stage in the process. Simon Michaux at the Geological Survey of Finland is skeptical. He thinks that although the circular economy is a great idea, it could only ever source a small part of what is needed. "The amount of copper mined between 1990 and 2023 was 520,000,000 metric tons," he points out. "All of that was produced into goods used and then thrown away. If we were to get out there and extract all that copper off all those waste dumps, put it all together, recycle and refine 100% of it, it would still be a fraction of the amount needed to produce just one generation of technology to phase out fossil fuels."

One of the challenges is that these material supplies only become viable at scale once vehicles reach end-of-life. Also, some recycling operations make use of quality control fail cells and scrap from the manufacturing process. In the early stage of the industry's development, access to primary raw materials will still be essential.

The main challenge is the cost of EV batteries, says McKinsey & Company's Andreas Breiter. "To overcome that, incentives and a regulator push can help in combination with innovation," he believes. "That can mean recycling more of the materials in the batteries to make them more affordable. Innovation in battery chemistry is important because the more we increase the energy density of the battery, the more efficient and lighter the vehicle becomes.

I think it is a combination of bringing down the cost, continuing innovation and building up the supply chain to make sure there are no major interruptions or price spikes."

CHEMISTRY SET

Innovative technology and new chemistries may hold the key to reducing dependence on a range of ever rarer minerals that are not abundant or even present close to where they are needed.

For example, lithium nickel manganese cobalt oxide (NMC) uses nickel-rich materials that offer higher energy density while reducing reliance on cobalt, which is not only rare but also comes with political challenges and humanitarian concerns related to its extraction.

"Next-generation technologies such as lithium-sulfur and sodium-ion batteries, with their potential for lower costs and use of more abundant raw material sources, could play a significant role over the longer term by reducing reliance on scarce raw materials and helping to alleviate supply chain bottlenecks," suggests Gifford.

Hartley sees a shift toward lithium-ion phosphate (LFP) batteries that are not so mineral dependent. "In Europe, a number of producers have announced they are beginning to focus on LFP to compete with lower-cost cells produced in China," he reports. "For example, LGES announced it was adding LFP production lines at its plant in Poland to supply Renault. Also, ACC is reportedly considering switching to LFP due to fierce price competition and weaker-than-expected EV demand in Europe."

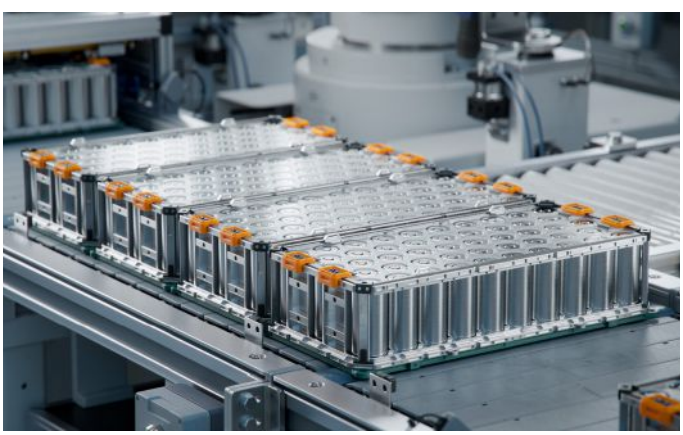
Even accounting for secondary sources of raw materials from recycled batteries, Hartley still anticipates the need for new mined supply to keep up with demand. However, this doesn't mean that recycled materials won't be important within the supply chain.

SUPPLY AND DEMAND

The development of lithium-ion manufacturing capability across Europe will be critical to serve domestic automotive markets and compete with China and the USA, says Gifford. "The phasing out of petrol and diesel vehicles is already harmonized across the UK and Europe and this will help drive European demand and supply," he notes. "Cross-border initiatives to secure critical raw materials, as well as European-wide collaboration on long-term R&D programs to improve cost-competitiveness and battery performance will help deliver what industry requires."

The EV battery supply chain is not straightforward. It is governed by the location of mineral deposits relative to battery and vehicle manufacturing plants, fluctuating demand due to legislation and commercial acceptance, over- and under-supply and the instability of international politics. That unpredictability is a major challenge.

Shortening supply chains is favored across logistics-dependent industries, particularly where the timely delivery of raw materials and components is critical to manufacturing and onward chains. How to achieve this in the automotive EV market will no doubt be the focus of discussion in many boardrooms in the coming years. ⦿



ABOVE: Salt Lake City in Utah has promise as a source of battery raw materials

LEFT: Getting to the finished article – cells in modules – ready for fitment into a battery pack requires negotiation of complex supply chains

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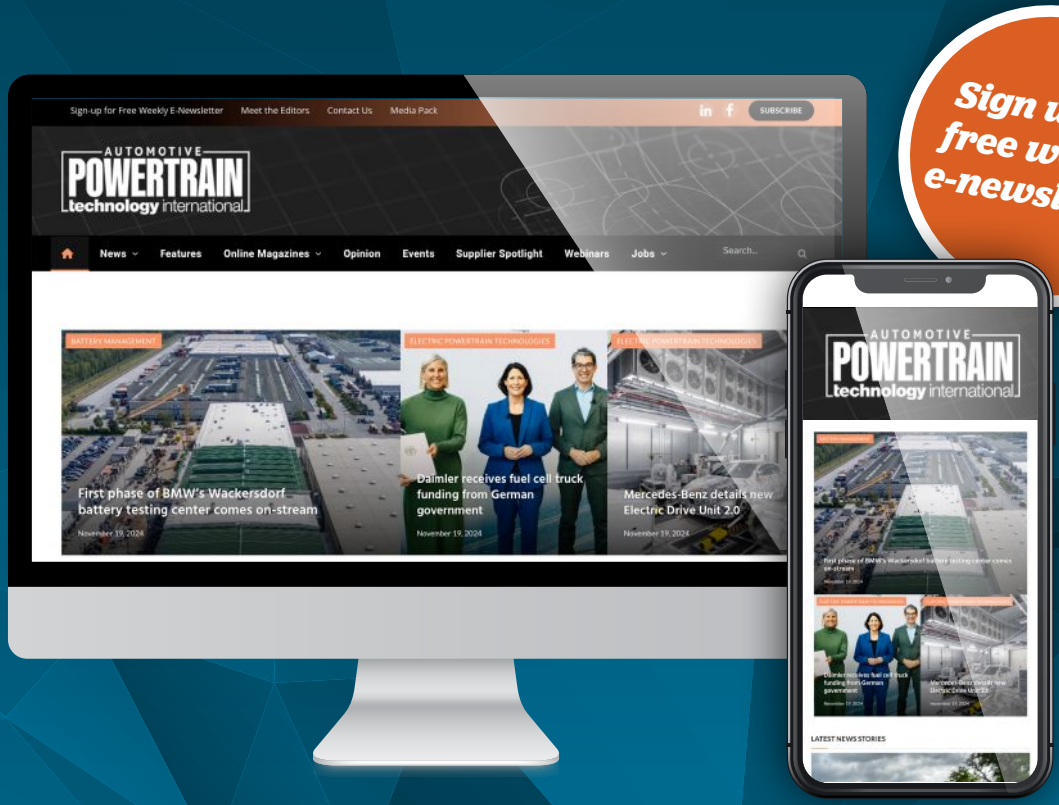

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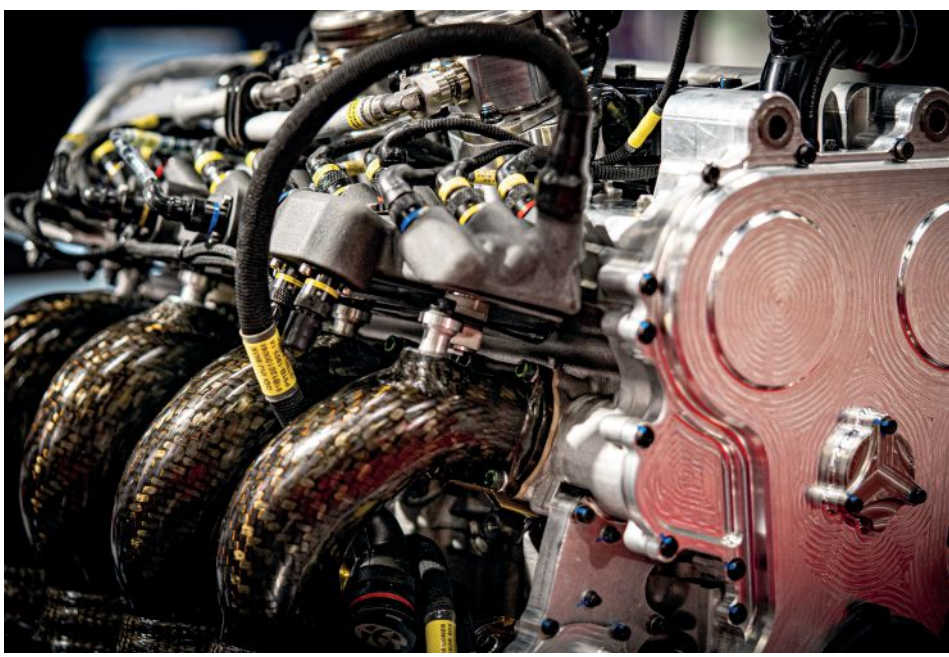
Expo highlights

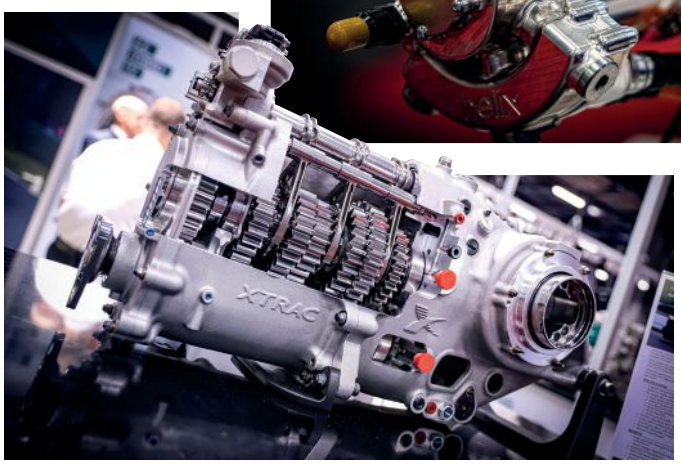
THE ANNUAL GATHERING OF HIGH-PERFORMANCE ENGINEERING SUPPLIERS PROVIDED A SMORGASBORD OF POWERTRAIN TECHNOLOGY FOR VISITORS TO ENJOY

Words: Lawrence Butcher

The annual PMW Expo takes place every November in Cologne, Germany, providing a hub for engineers within the motorsport and high-performance automotive industries to come together and exchange ideas.

The show always features a host of advanced powertrain solutions, and 2024 was no different. From high-end combustion engines to high power-density battery systems and bespoke transmissions, the expo floor was littered with treats to excite a powertrain engineer. With the addition of a dedicated Advanced Powertrain Technology Forum this year, there were technical innovations on show covering every conceivable energy type and application. *APTI* picked out some of the highlights.





Shooting for the stars

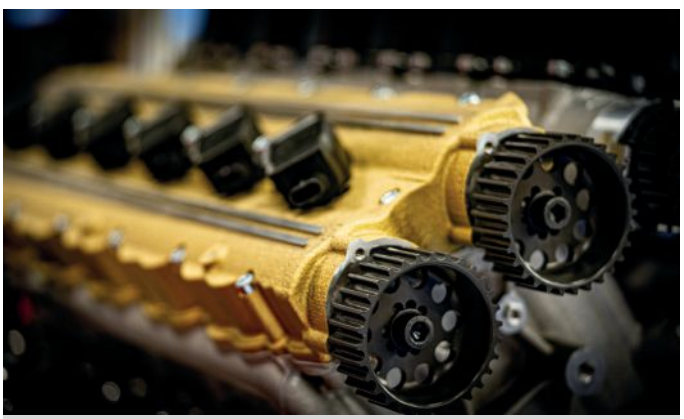
Cosworth launches new range of Antares ECUs

Cosworth launched the Antares 4 and Antares 6 ECUs at PMW Expo and secured the Powertrain Technology of the Year award in the process. The new ECUs bring the advanced capabilities of Cosworth's top-end Antares 8 unit to a wider array of motorsport applications.

The Antares 4 and 6 are designed and developed for OEMs, motorsport teams and individuals. They can function as a complete vehicle controller and datalogger, all fully supported by Cosworth's well-established software toolchain. The ECUs retain all the control capabilities of the flagship Antares model.

Both ECUs can support a range of powertrain technologies, including IC engines, hybrids, plug-in hybrids and BEVs. Along with these control capabilities, Antares 4 and 6 also offer high-rate synchronized datalogging for precision and reliability. They also come equipped with control features such as multipulse and stratified GDI control, active torque management and FIA-compliant real-time PPU and BOP control.

For teams in need of advanced customization, Cosworth's real-time embedded software-generation platform enables the development of bespoke algorithms within the MATLAB Simulink environment. This enables teams to deploy complex powertrain and chassis control algorithms, signal processing routines, dynamic models and ultra-high-speed data processing within the development toolchain.



Italian artisan

New V12s from Turin engine builder

Turin-based Italtecnica always brings something to titillate powertrain aficionados at the expo and this year was no exception.

The company is working on several V12 projects and displayed some of the component parts of what will be a naturally aspirated 12-cylinder. It has also developed a monster 7-liter, quad-turbocharged, 120° V12 for an undisclosed customer, due to be revealed in 2025.

Advanced Powertrain Forum

Experts gather to discuss BEV, ICE and fuel cell propulsion systems

A brand-new addition to PMW Expo in 2024 was the Advanced Powertrain Technology Forum, which brought together a range of experts from across the world of motorsport and high-performance automotive.

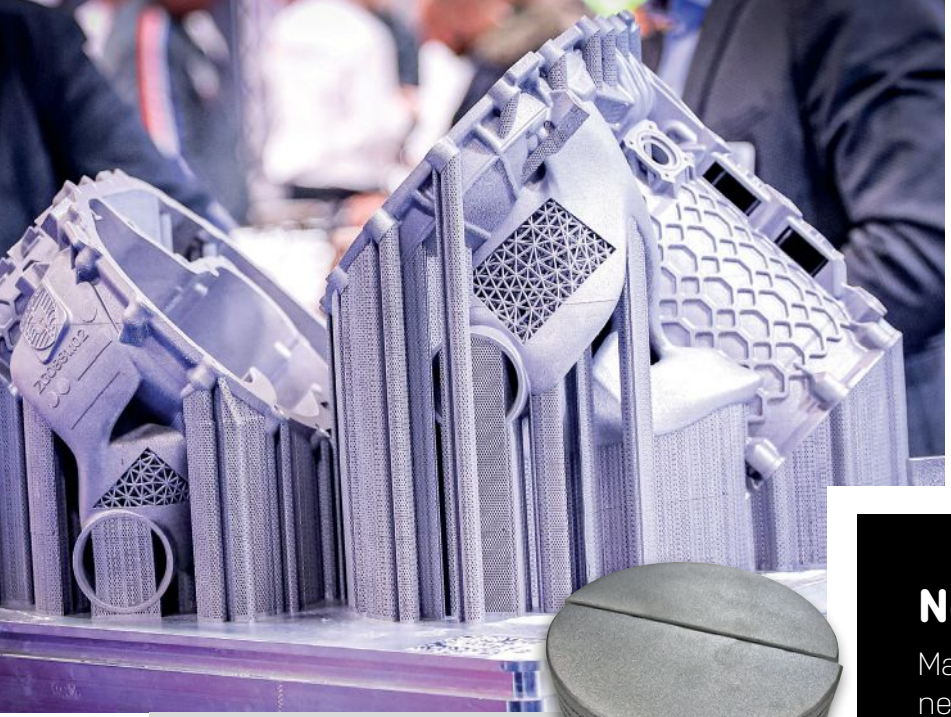
Hydrogen was the subject of several presentations. Alpine's Pierre-Jean Tardy provided some excellent insights into the company's ongoing development of hydrogen ICE technology via its Alpenglow racing concept. Addressing the specific challenges of extracting comparable levels of performance from hydrogen ICE compared to gasoline, his presentation delved into the specifics of materials compatibility, ensuring turbocharger responsiveness despite low exhaust gas temperatures, and much more.

Continuing the hydrogen theme, the student-led Forze team, hailing from TU Delft in the Netherlands, presented the latest work on its fuel cell-powered sports prototype. Now on its ninth iteration, the car features two fuel cells with a combined output of 240kW, which feed a buffer battery capable of releasing up to 600kW to the traction motors. Much of the team's work has focused on optimizing the packaging and efficiency of the fuel cell balance of plant, along with extensive development of the car's onboard control systems.

Another highlight was Damien Harty's presentation looking at the challenges of torque vectoring in electric vehicles. He provided some fascinating insights into the control techniques that can be applied, and the close working relationship that is required between powertrain and chassis development teams.

In a similar vein, Williams Grand Prix Technologies' Selin Tur took on the topic of multiphysics simulation, in particular its application to battery electric powertrains. This included a dive into the application of mainstream AI tools such as ChatGPT and how these can be harnessed for serious powertrain development work.

The Advanced Powertrain Technology Forum highlighted the rapid pace of development in high-performance powertrains, regardless of energy type, and will return for 2025 to provide visitors with further exclusive insights. More detailed reports on the workshops will be available on the *Automotive Powertrain Technology International* website soon.



Neural novelty

Marelli Motorsport has integrated a neural processing unit into a vehicle and engine control unit

Marelli Motorsport scooped the Powertrain Technology of the Year award and Overall Engineering Innovation of the Year award for its VEC_480 ECU. The unassuming unit packs a phenomenal punch, incorporating not only vehicle and engine control functions but also an in-built neural processing unit, capable of 26 TOPS. The result is effectively an edge computing solution integrated into an ECU (hence the name VEC – Vehicle Edge Controller).

"The idea is to integrate a vehicle control and engine control unit with the possibility to implement AI-based algorithms to enhance the functionality," explained Ricardo de Filippi, CEO and SVP of Marelli Motorsport. "You can do vehicle sensing, real-time energy optimization, any crazy idea you can come up with. We think it is a game-changer, and comes from our experience we have with our customers asking for more and more power, and part of that was to implement neural-based algorithms."

Additive insights

AM technology is ready for series production

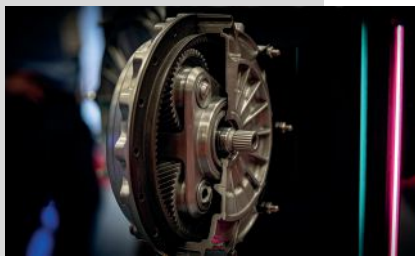
Another new addition to PMW Expo for 2024 was a dedicated additive manufacturing zone, where various experts in the field had a range of solutions on display, including a host of AM powertrain parts. From more obvious applications such as exhaust manifolds with complex geometries, through to fully metal-printed cylinder heads and transmission casings, the zone highlighted the rapidly advancing capabilities of additive manufacturing technology.

"The message here today is that the technology is ready for series production," said Ralph Frohwerk, global head of business development at Nikon SLM Solutions. "It is extremely important to understand that this technology is capable of fulfilling automotive requirements and being certified for production, and is already being used in series production with some of our partners."

Elemental engagement

Ricardo's new range of epicyclic EV transmissions

Transmission specialist and engineering consultancy Ricardo chose PMW Expo to launch its latest product line, Element, a range of three epicyclic transmission systems intended to provide an off-the-shelf solution for developers of high-performance electrified powertrains.



Powertrain insights

Exhibitors at PMW Expo share their knowledge

In addition to the dedicated Advanced Powertrain Technology Forum, a second stage at the expo provided a venue for exhibitors to showcase their technology. Covering the gamut of vehicle systems, powertrain innovations featured heavily.

Leaders in their respective fields – such as Xtrac – delved into the details of high-performance transmission design, while experts including Dr Dieter Hofler, CEO at tectos, looked at more esoteric subjects including the management of NVH in race cars.

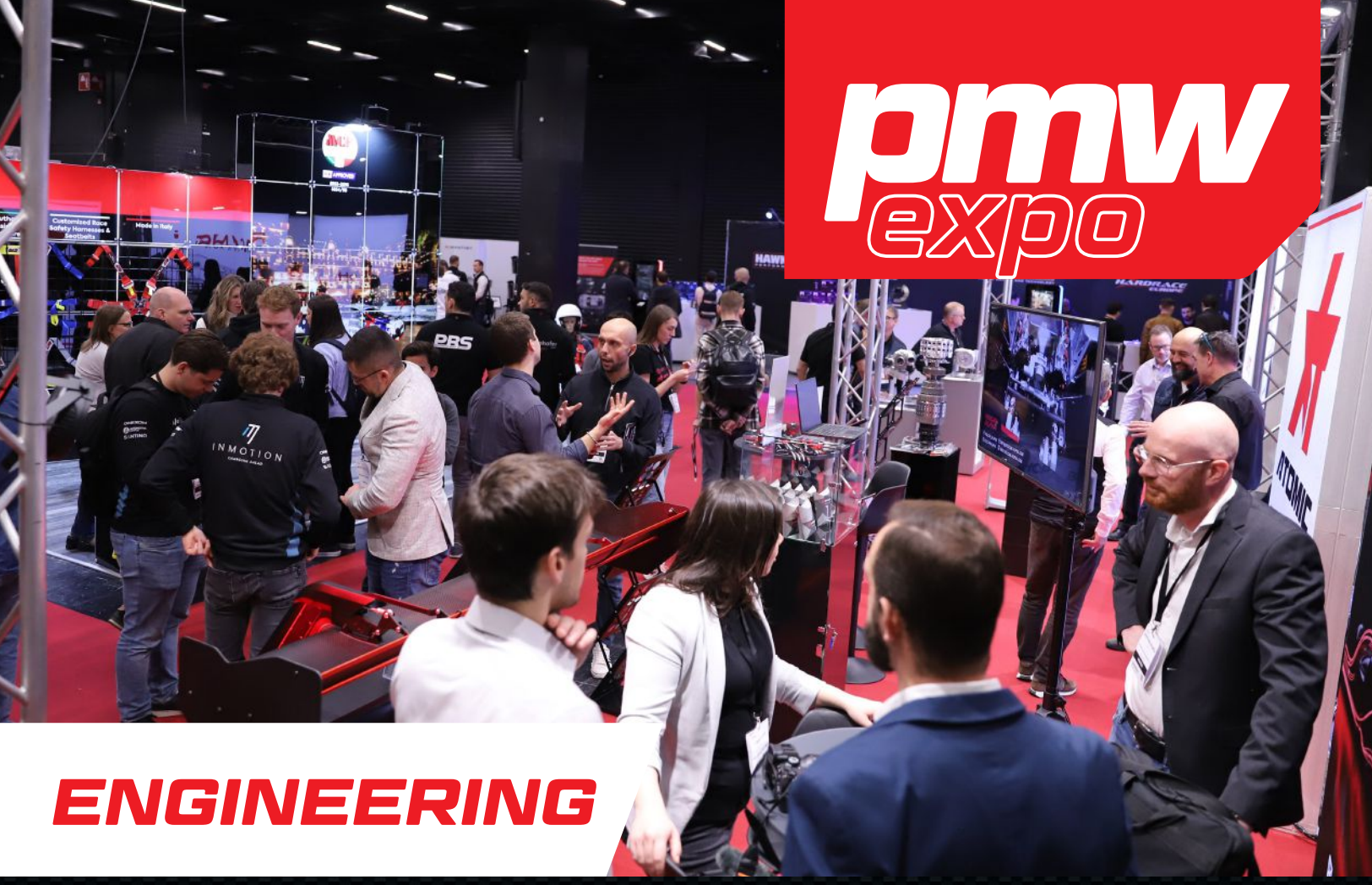
Advanced vehicle control and telemetry systems featured heavily, including a presentation on McLaren Applied's latest offering, the VCU500 and associated ATLAS software system.

Hammer time

Elmer Racing's Thor engine

With five back-to-back World Time Attack championships under its belt, Elmer's Thor engine – on display at the expo – highlighted just how far even conventional ICE technology can be pushed for competition use. Developed and manufactured in under eight months at very low cost, Thor is claimed to offer the highest power/mass ratio of any circuit-racing engine. The inline-four is capable of over 2,000bhp, with an all-up weight of 150kg.

pmw expo



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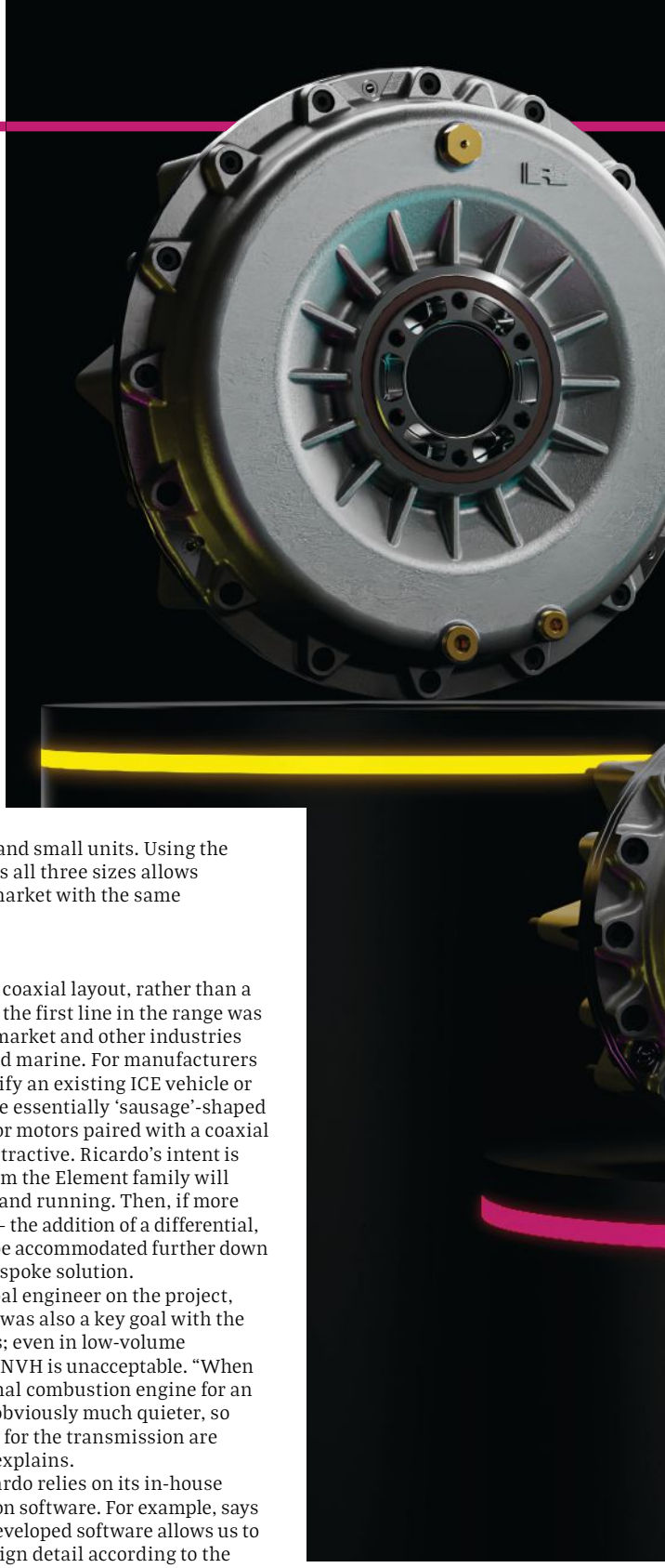
Elemental approach

RICARDO HAS TAKEN A MODULAR APPROACH TO TRANSMISSIONS FOR HIGH-PERFORMANCE EVs

Words: Lawrence Butcher



Ricardo's Element transmission series covers a range of motor power, torque and speed applications

UK-based Ricardo has long been recognized as a leader in the development of high-performance transmissions and powertrains. However, the company also has exceptional credentials as an environmental engineering consultancy. This combination means that it has not only the technical know-how to develop truly next-generation powertrain solutions but also the in-house expertise to understand the opportunities for their adoption across a range of markets.

Ricardo's latest release, the Element series of epicyclic transmissions for electrified vehicles, is an excellent example of this approach. It is Ricardo's solution for companies looking to develop electrified powertrains for low-volume, high-performance production applications. "We know that as the world moves toward decarbonization, BEV and hybrid is coming more to the fore. Having had some experience with epicyclic [transmissions] on several bespoke projects, we realized that there was a requirement for something that was more universally available to the market," says Steve Blevins, head of engineering. Ricardo Performance Products.

Element consists of three modular options for high-, medium- and low-torque applications and motor speeds from 10,000rpm up to 25,000rpm. The transmissions are designed to be compatible with a range of motors currently available to the market, including those of Helix and Empel, two well-known purveyors of high-performance e-machines.

"Development times [in the automotive industry] are being compressed and shortened," notes Blevins. "We did a market sweep of high-performance vehicles and out of that came the three different sizes, for different torque capacities and powers, and a suite of ratios. With an e-machine, you can change the performance easily by using a longer rotor and extra set of magnets, and we adopted a similar philosophy for the transmission."

The result is that the same basic design approach can be used across all three versions, with the components simply sized up or down to meet the torque requirements. "This means that the intricacies we learn from one size, we can carry across the entire range," says Blevins. "For example, we have taken our learning on how we control the oil within the medium-size unit and applied those principles to the large and small units. Using the same philosophy across all three sizes allows us to cover the entire market with the same basic approach."

COAX ROUTE

The choice to go with a coaxial layout, rather than a parallel-axis setup, for the first line in the range was led by the automotive market and other industries such as off-highway and marine. For manufacturers looking to either electrify an existing ICE vehicle or scratch-build a BEV, the essentially 'sausage'-shaped form factor of a motor or motors paired with a coaxial transmission is very attractive. Ricardo's intent is that a transmission from the Element family will get a manufacturer up and running. Then, if more complexity is required – the addition of a differential, for example – this can be accommodated further down the line with a more bespoke solution.

As Jiří Jager, principal engineer on the project, points out, refinement was also a key goal with the Element transmissions; even in low-volume applications, excessive NVH is unacceptable. "When you exchange an internal combustion engine for an electric machine, it is obviously much quieter, so the NVH requirements for the transmission are more demanding," he explains.

To address this, Ricardo relies on its in-house expertise and simulation software. For example, says Jager, "Our in-house-developed software allows us to quickly finesse the design detail according to the transmission demand, such as increasing the contact ratios and refining the gear micro-geometry. We can no longer assume the rest of the powertrain will mask any noise emanating from the transmission."

Another interesting aspect of the Element transmissions is that all can share cooling provision with their motors. "One of the features that we've tried to do on the motor side of the reduction unit is to try to provide a spigot diameter and something of

> We did a market sweep of high-performance vehicles and out of that came the three different sizes, for different torque capacities and powers, and a suite of ratios"
>
> **Steve Blevins, Ricardo**

a generic mounting arrangement," says Blevins. "We know from some of the other projects we've worked on that the machines can be cooled with a collar that goes between the gearbox and the e-machine, so we are prepared to use that shared cooling arrangement." Shared lubrication between the motor and transmission is not yet an option, though Ricardo has been involved in several projects investigating this approach and it's an area within the company's expertise.

While the primary market for Element is automotive, the breadth of performance covered by the concept is such that it could just as easily be applied to a marine application such as a pod-mounted propulsor or an off-highway vehicle. "Everyone knows us for automotive and racing products, but Ricardo as a group is heavily involved in environmental consulting," notes Blevins. "We see a lot of applications in off-highway and we're working on some decarbonized military projects as well. There are a lot of opportunities in marine, while the agricultural and industrial markets are other massively untapped areas."

Summing up the capabilities of the Element series, Blevins says, "We have a range of three differently sized units that, in combination, can handle the spread of torque we know the marketplace demands. Within each size we have the capability of refining the torque capacity by altering the gear face widths and the ratio reduction through it. This offers myriad combinations. With a 'single' planet arrangement we can handle ratio options of between 4:1 and 7:1 reduction. To achieve a greater reduction ratio, up to 10.2:1, we can adopt a 'compound' planet arrangement. These variables allow us to customize the gearbox to suit individual customer requirements. Fully bespoke units can also be considered, if required. However, we do offer a few 'standard' ready-to-manufacture units of fixed ratio and torque capacity, which could suit many applications. These will allow our customers to get programs up and running with minimum delay."

Ricardo's Chris Kodagoda, market head for high-performance vehicles, points out that the company is a full-spectrum service provider, so customers are not just buying a transmission. "We have in-house capabilities that allow us to provide bespoke testing requirements and validation. Depending on what the customer needs in terms of timing and budgets, we can tailor-make a validation program for them based on a standard unit. If that process finds that they need a different requirement, then we can talk about a more bespoke solution."

The core concept of Element is to provide customers with an easier route to electrification, as Kodagoda sums up: "There are customers facing the challenge of decarbonization and trying to move in that direction, but they don't have the know-how or experience to do transmission development. That's where we can step in and support and guide customers throughout the entire process." ⦿

The importance of temperature control in automotive R&D testing

Ensuring components can withstand thermal rigors through their lifespan requires the correct temperature control solutions

Within the automotive industry, temperature control is mainly found in test and inspection rigs, as well as material tests. All the components of an automobile are exposed to extreme temperature fluctuations to ensure that they function correctly and reliably during subsequent use. This process of testing many different components in special test rigs makes an important contribution to improving quality and reliability.

The simulation of extreme environmental conditions across a wide range of temperatures is an important part of the material tests. Climatic chambers are used to simulate ambient temperatures, while process thermostats control the temperature of the coolant to simulate cooling circuits in the vehicle. As a result, the heat flow in the test specimen can be controlled via temperature gradients.

Lauda has been providing temperature control solutions for many industries for over 60 years. Its presence within the automotive R&D workplace is ever-growing, providing temperature control across a wide range of set-point temperatures.

DC-DC CONVERTERS AND TRACTION INVERTERS

Devices such as DC-DC converters and inverters are key components of the drives used in electromobility. To test their reliability and efficiency, they are exposed to different climatic influences. Lauda constant-temperature equipment and systems run through the required temperature profiles within a test temperature range of -40°C to +140 °C and reliably adjust the load conditions.

Onboard chargers

Onboard chargers (OBCs) in electric vehicles must undergo thermal testing as they are critical to safety and performance. These chargers convert alternating current into direct current, generating heat in the process. Excessive temperatures can damage components, reduce efficiency and shorten the life of the system. Thermal tests simulate extreme operating conditions to ensure that the OBC has sufficient cooling and functions reliably, even in high outside temperatures or intensive use. This ensures compliance with safety standards.

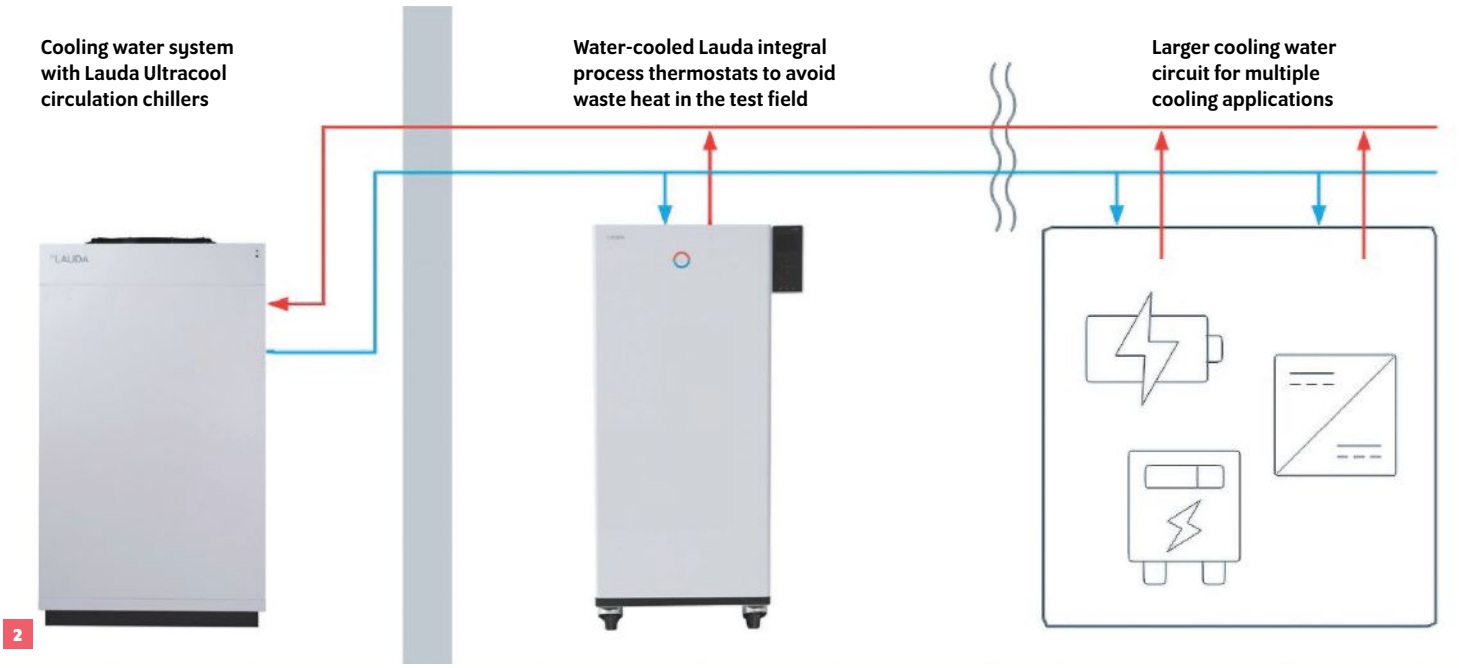
1. A Lauda integral XT process circulator connected to a dyno test rig, providing temperature control via the circulation of fluid to and from the rig

EV BATTERIES

Battery performance is a key element of electric mobility. Charge levels, charging cycles and performance are tested in climatic chambers at varying ambient temperatures. Lauda's constant-temperature equipment and systems control and monitor the temperature to simulate varying operating conditions and determine whether they have any impact on battery performance.

LIQUID-COOLED CHARGING CABLES

The use of liquid cooling technology in high-power DC charging cables helps maintain a constant low temperature during charging, preventing thermal damage to the cable and connector caused by overheating. To ensure safe and efficient operation of liquid-cooled charging cables, rigorous thermal and electrical performance testing must be conducted.


Cooling water system with Lauda Ultracool circulation chillers
Water-cooled Lauda integral process thermostats to avoid waste heat in the test field
Larger cooling water circuit for multiple cooling applications

2

ELECTRIC DRIVES

The engine and its cooling system must work reliably and efficiently under different operating conditions. Lauda's integral process thermostat plays a key role in this by providing the precise temperatures required for reproducible and controllable test conditions.

Parts and components for vehicles are tested for their resilience under extreme conditions using climate and temperature tests. With powerful, variable-pressure pumps and direct use of automotive coolant, Lauda's constant-temperature equipment and systems pass these stress tests with flying colors. Thanks to the integration of a Lauda flow control unit, these tests are more precise and can be reproduced more accurately. This ensures the high quality of the components.

The most popular constant-temperature equipment requested by customers in the automotive sector includes circulation chillers and thermostats. These are ideally suited to reliably and precisely carry out activities such as service life tests for batteries and electronic components, end-of-line testing for e-mobility components, test benches for electric motors and endurance testing for fuel cells.

On request, Lauda's temperature control solutions for the automotive sector can be adapted to suit the prevailing requirements and customers' wishes. The company's individual temperature control systems can be flexibly extended and modified and are developed individually according to customer requirements.

In the automotive industry, test benches, aging tests, quality control and the examination of various engine components are part of daily business. Test engineers must always be able to rely on correct temperatures during testing, enabling accurate assessment and validation of the device under test. With Lauda's temperature control units for the automotive industry, they can achieve this.

Lauda's product range includes many units to keep temperature control processes in the automotive industry up to date.

2. A typical setup for a water-cooled integral XT and its application indoors, receiving its cooling water from a Lauda Ultracool chiller located outdoors

3. Lauda integral XT process circulators providing temperature control for climatic tests chambers

Lauda
To find out more, scan the QR code or visit:
www.lauda.de

EXAMPLES

Lauda's integral process thermostats are used in the automotive industry and by many testing service providers to test batteries, power electronics and e-drives, often in combination with Lauda flow control or Lauda filling and drain units.

Its Ultracool circulation coolers are ideal for providing central cooling water for integral process thermostats and ensure a high cooling capacity, even in continuous operation. They are suitable for outdoor installation and have a temperature monitor that reliably protects the heat exchanger.

Lauda plans and builds systems precisely in accordance with customers' wishes. They are process oriented, made to measure and precisely in accordance with regulations and strict safety standards. Since the requirements for constant-temperature equipment are continuously growing, the modern Lauda heating and cooling modules are also flexible as far as expansion and modification are concerned. ⦿

3

Accelerating speed-to-market for EV manufacturers

The complexity of the electrification journey requires an expert partner to help navigate it

With continued market growth and rapid technological shifts predicted, getting EVs to market faster is a critical priority for manufacturers around the world. For Intertek, a leading total quality assurance expert, helping OEMs on this journey is an everyday occurrence. Intertek Transportation Technologies is positioned to provide insights into how a strategic approach to assurance, testing and certification can help clients succeed in the race to electrification.

NAVIGATING REGULATORY COMPLEXITY IN A RAPIDLY EVOLVING ENVIRONMENT

While the rapid pace of technological development is creating exciting opportunities to bring cutting-edge new products to market, a highly complex global regulatory environment presents challenges in quickly getting these new EVs on the road.

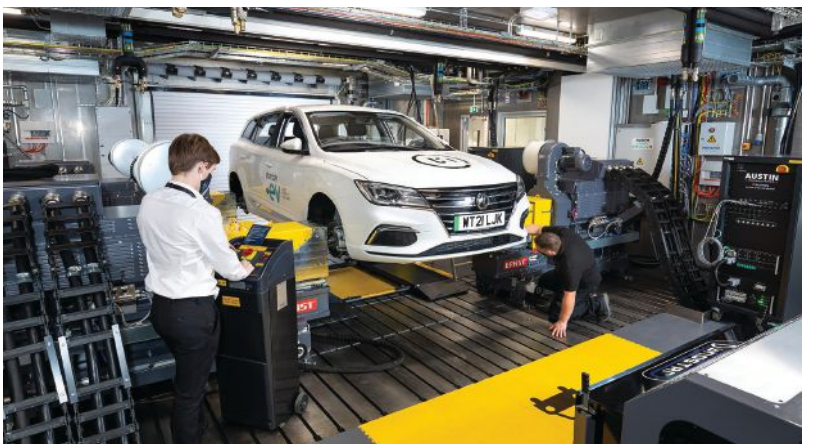
Regulations and standards are often seen as the final hurdle at the end of a long development process. However, they should be considered at every stage of product development. For EVs, the differing and evolving regulations around the world present a challenging landscape to navigate. Globally, there are multiple regulatory and legislative standards that need careful interpretation.

Keeping up to speed with these requirements and their impact on product design and specifications is a significant undertaking. Getting it wrong can lead to costly mistakes. Working with an expert partner like Intertek not only ensures companies have access to the latest knowledge and expertise but also gives them the opportunity to ensure they are designing regulatory compliance into product development at the earliest stages, so they don't waste time or resources.

ENSURING SAFETY, QUALITY AND RELIABILITY ACROSS THE EV ECOSYSTEM

Electric vehicle technology isn't just about batteries. The EV ecosystem brings together a wide variety of technologies, both existing and new. From EV powertrains to new fuels and lubricants, or how different charging infrastructure interacts with specific vehicles, the diversity of innovations represented in any one vehicle can be significant.

As always, safety and reliability are paramount. In a product where many elements are new or improved, the risks of going to market too quickly can be high. Intertek offers testing solutions covering the entire EV ecosystem, from battery cells all the way through to charging infrastructure and everything in between. These solutions ensure that every aspect of a vehicle is safe, reliable, optimized for performance and compliant with each geographic market's regulatory requirements. Meanwhile, Intertek's global network of experts and market-leading turnaround times mean clients can still move forward at pace.



Intertek's EV Centre of Excellence in Milton Keynes, UK, is part of its global lab network

SUBSTANTIATING MANUFACTURING CLAIMS WITH REAL-WORLD PERFORMANCE

Performance, such as range and charging time, is a top priority for consumers and can make a big difference when it comes to choosing a particular vehicle or 'going electric' at all. However, these performance metrics, especially for batteries, often differ when tested in real-world conditions rather than controlled environments.

An expert testing partner is essential to enable extensive testing under a diverse range of conditions and ensure that product claims are backed by accurate data gathered from both the laboratory and the road.

ENABLING SPEED AND AGILITY IN A HIGHLY COMPETITIVE MARKET

Bringing a vehicle to market is a complex process. EV manufacturers will need to be agile to win in the race to electrification. While speed-to-market might be critical, so too is ensuring safety, quality, performance and reliability. Success requires a considered, coordinated approach and the right total quality assurance partner.

Intertek's market-leading expertise, cutting-edge testing facilities and best-in-class turnaround times provide EV manufacturers and suppliers with the knowledge and capabilities needed to stay ahead.

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Precise fluid control for transmission applications

Increasing performance in automotive transmissions is about maximizing efficiency while minimizing footprint

Design engineers are tasked with improving fuel economy by developing more responsive transmissions while reducing the size and weight of corresponding subsystems. Although advances in transmission design have improved system efficiency, demands for better fuel economy and lower emissions mean that older solutions may not meet the design challenges of an evolving – and increasingly electrified – automobile market. Thanks to their innovative designs, The Lee Company's components help auto makers meet the performance and reliability standards required for next-generation transmissions.

DESIGN CHALLENGE: HIGH PRESSURES IN TRADITIONAL TRANSMISSIONS

Historically, vehicle designers have improved efficiency in automatic, continuously variable and dual clutch transmissions by adding gears and gear ratios to amplify torque and boost fuel economy. As design trends evolved, system pressures increased to accommodate the needs of higher-speed transmissions and minimize weight. The Lee Company has developed components specifically for these high-pressure applications. Its pressure-relief valves provide quiet, stable pressure control to protect systems from over-pressurization or pressure spikes. They offer higher flows in a smaller envelope than other traditional valves or in-house ball and spring designs.

Miniature Lee check valves are rated for high pressures to prevent leakage. Designed for durability, they succeed where in-house solutions fail due to intense pressure or poor casting designs.

Lee expansion plugs provide a leak-tight seal without secondary retention methods, delivering repeatable performance even under the highest pressures. Plugs are available in a variety of styles, sizes and materials and are rated for pressures from under vacuum to 483 bar.

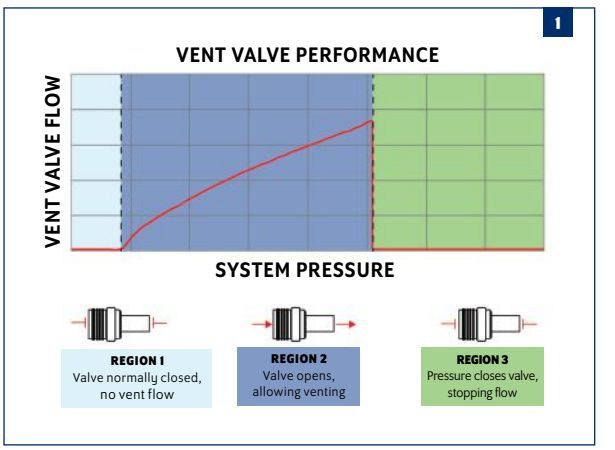
DESIGN CHALLENGE: LOW PRESSURES IN ELECTRIC VEHICLE DRIVE UNITS

EVs use electric drive modules, electric drive units or e-axles to distribute torque within the vehicle. These applications require significantly lower average pressures than internal combustion engine transmissions. While design engineers may be tempted to use solutions from cooling systems – which have similar pressure profiles – here, these components may not offer the same precision or performance with oil as they do with water. In addition, traditional cup or freeze plugs pose a significant leakage risk when used as external plugs.

The Lee Company offers components to replace traditional cup or freeze plugs in electric vehicle drive units. These components feature visual indicators to confirm proper installation and do not require the use of adhesives – which add unnecessary cure time and cost, as well as an additional processing step. The Lee Betaplug is a pre-assembled expansion plug designed to seal cross-holes leak-tight without threads, O-rings or sealant. In some cases, in-house cooling jets are made by drilling large holes in cup plugs. These parts may fail to produce adequate or targeted flow to specific areas in the gearbox at lower pressures. Lee targeting orifices allow designers to cool hot spots in gearboxes with more precision, and therefore less coolant, compared with these in-house cooling jets.

1. The vent valve purges air from the system during startup and prohibits air from being drawn back in while the system is shut down

2. The Lee Company offers innovative fluid control components that help vehicle designers save space and weight in their transmissions



DESIGN CHALLENGE: AIR MANAGEMENT IN THE MODERN TRANSMISSION

Air can be a serious issue for any type of hydraulic system – whether within an automatic, dedicated hybrid transmission or an electric vehicle. The Lee Air Bleed Orifice removes trapped air while minimizing hydraulic pressure losses. It contains a small precision flow orifice that is ideal for removing a small amount of air trapped at a high point. Lee vent valves can purge large amounts of trapped air from systems during startup events. This normally closed valve opens to release air as the system is pressurized and closes once the operating pressure is reached.

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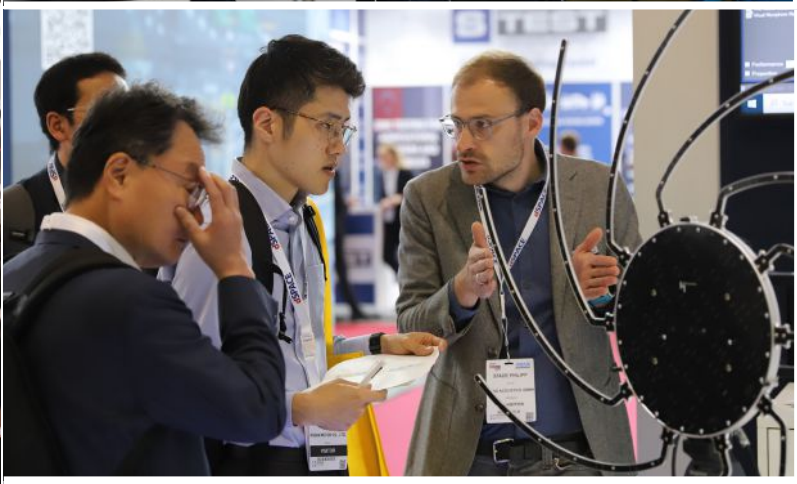

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Protecting zonal electronics

The increasing complexity of vehicle electronics architectures requires new approaches to protection

With the evolution of electric vehicle architecture, electronic control systems face increased demands. A significant shift is the move from traditional distributed control systems to zonal control units (ZCUs), which simplify wiring, reduce weight and improve efficiency. ZCUs, which manage multiple electronic control units within specific zones, are being considered for EV powertrains, managing power distribution, battery management and motor control. This article addresses how to protect ZCUs from electrical hazards to ensure their reliable operation in EV powertrains.

ENHANCING CONTROL

In traditional vehicle systems, powertrain management relies on dedicated control units for the battery, motor and inverter. ZCUs offer a more modular approach by managing specific powertrain functions – such as torque control and battery monitoring – within each zone. By centralizing control and reducing wiring complexity, ZCUs can improve powertrain efficiency. For instance, ZCUs can optimize battery thermal regulation and energy use, simplifying the vehicle's overall system architecture.

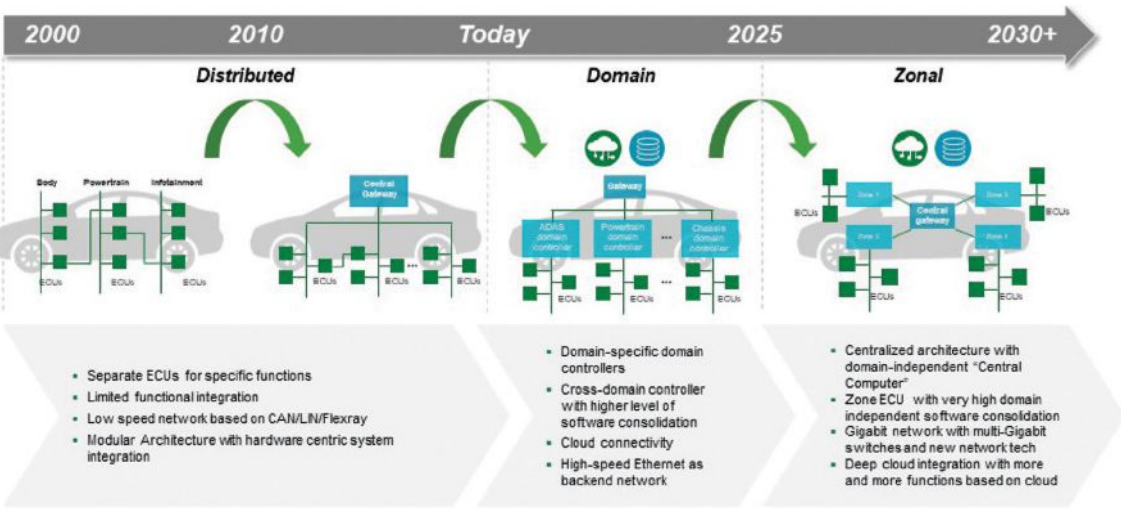
However, ZCUs in powertrains face electrical hazards, such as high voltages, inductive loads and extreme temperatures, which must be addressed to ensure performance and longevity.

PROTECTING THE DC-DC CONVERTER

The DC-DC converter is vital in any ZCU, stepping down the 12V input to the lower voltage levels required for digital circuits. It must be protected from overcurrent and transient voltage surges to prevent damage to downstream components.

Fast-acting fuses such as the Littelfuse AEC-Q200-qualified surface-mount fuses offer compact protection and handle temperature ranges from -55°C to +150°C. Furthermore, PPTC resettable fuses automatically

1



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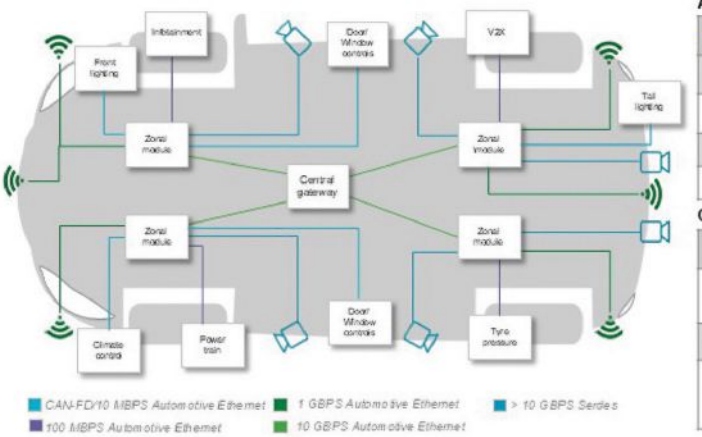

Automotive Ethernet standards:

OPEN ALLIANCE	10Base-T1S IEEE 802.3cg	100Base-T1 IEEE 802.3bw	1000Base-T1 IEEE 802.3bp	MGBase-T1 IEEE 802.3ch
Data rate	10 Mbps	100 Mbps	1000 Mbps	2.5/5/10 Gbps
Symbol rate	12.5 MHz	66 MHz	750MHz	1.4/2.8/5.6 GHz
Distance	15/25 m	15 m	30 m	15 m
#Lanes	1	1	1	1

Comparison of technologies:

Features	Automotive Ethernet	CAN/CAN-FD/CAN-XL	LIN
Data rate	10 Mbps–10 Gbps	1 Mbps (CAN) 8 Mbps (CAN-FD) 20 Mbps (CAN-XL)	20 Kbps
Cable length	30 m	40 m	40 m
Applications	ECU interconnect, camera, radar, infotainment	ABS, powertrain, engine control	Electric seats, mirror adjustments

reset after clearing an overcurrent condition, making them useful in zones requiring continuous operation.

Metal oxide varistors (MOV) or TVS diodes protect against transient surges. Littelfuse MOVs, qualified to AEC-Q200, absorb inductive transients like load dumps, while TVS diodes respond rapidly and handle large surge currents.

INTERFACE PROTECTION IN THE POWERTRAIN ZONE

ZCUs in EV powertrains interface with critical systems, requiring protection from noise, surges and electrostatic discharge (ESD). Littelfuse offers a range of ESD diodes and TVS diode arrays for communication line and data signal protection.

Automotive Ethernet, often used in zonal architectures, also requires ESD protection for reliable high-speed data transmission. Littelfuse provides ESD suppressors that meet the Open Alliance SIG's stringent requirements, ensuring low capacitance and protection against high-voltage ESD events.

1. The evolution of automotive control architecture

2. Zonal communication structure and automotive Ethernet compared with other automotive communication protocols

ZCUs AND BATTERY MANAGEMENT SYSTEMS

ZCUs are also integral in BMSs, optimizing battery performance by balancing cell voltages and managing thermal stability. Protecting control circuits from overcurrent and voltage spikes is crucial for BMS efficiency.

As zonal control expands in EVs, ZCUs will increasingly manage powertrain functions. By using components such as fuses, MOVs and ESD suppressors, engineers can ensure the reliable operation of ZCUs in challenging environments. Partnering with experts such as Littelfuse can streamline design processes and ensure compliance with automotive standards.

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Flexible HIL test solutions to improve BMS

Flexible test and simulation solutions are needed to address pressing demands on BMS testing for automotive OEMs

1

As electric vehicles continue to advance, testing and validating their complex systems is becoming increasingly important. At the core of these vehicles lies the BMS – a sophisticated electronic system tasked with monitoring hundreds of cells and protecting the battery from damage. Validating BMS performance requires rigorous simulation across diverse operating conditions, early and often.

1 & 2. Pickering Interfaces provides a range of flexible solutions for HIL testing of battery management systems

2

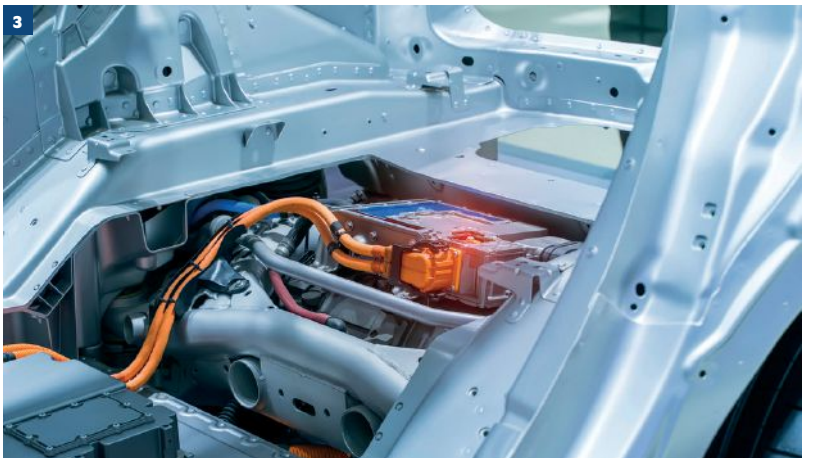
Pickering Interfaces, a leading supplier of industry-standard modular signal switching and simulation tools for use in electronic test and verification, has had recent success with flexible solutions for BMS testing.

"Our industry-standard modular solutions help auto makers move from design validation to production test of BMS," explains Noman Hussain, vice president of software and strategic business development at Pickering Interfaces. "Today's BMS demands can require testing of a single system every 15 seconds, 24/7 – our modules deliver consistent, reliable test results for accurate validation and verification."

SOLUTIONS FOR BMS VERIFICATION

Pickering provides effective solutions for automotive customers by offering platform-agnostic hardware and specific modules optimized for BMS testing.

Renowned French engineering manufacturing services provider MSL Circuits recently won a tender for the manufacture and test of battery management systems. The order was with a major automotive company that wanted all the BMS to be functionally verified as they came off the production line at a rate of four per minute. Having devised a test methodology, MSL turned to Pickering Interfaces for PXI battery simulation modules, chassis and support.



3. HIL testing enables manufacturers to accelerate the development of BMS

MAXIMIZING MULTIPLE TEST STANDARDS IN A SINGLE, MODULAR SOLUTION

Pickering enables long-term flexibility for test and simulation systems through support for open industry-standard platforms such as PXI and LXI. Unlike vendors tied to a single platform, Pickering provides PXI switching and simulation solutions that integrate into any vendor's PXI chassis – as well as its own LXI/USB chassis.

PXI excels when timing synchronization, speed and high density are critical, while LXI/USB provides simple and convenient control options via ethernet and USB interfaces. The ability to house multiple capabilities within a single unit streamlines the testing process, reducing complexity and enhancing flexibility. Workloads can be optimized by partitioning to meet density, timing and cost demands. Pickering also simplifies test creation through unified software for PXI and LXI systems – engineers can use the same application to control LXI and PXI instruments without switching drivers or changing test setups.

IDEAL MODULES FOR BMS TESTING

Pickering solutions for BMS testing include high-current, high-density fault insertion modules to simulate various faults when validating BMS, ECU or powertrain performance in a HIL system.

The company can also supply RTD simulators, which are modules for simulation of resistance-based temperature sensors, including PT100 and PT1000 RTD sensor types that require fine setting resolution. Then there are thermocouple simulators that can be used for sensor emulation in ECU testing, and battery simulator modules, which simulate the voltage and current of Li-ion batteries during charge/discharge cycles, now with increased voltage isolation up to 1,000V.

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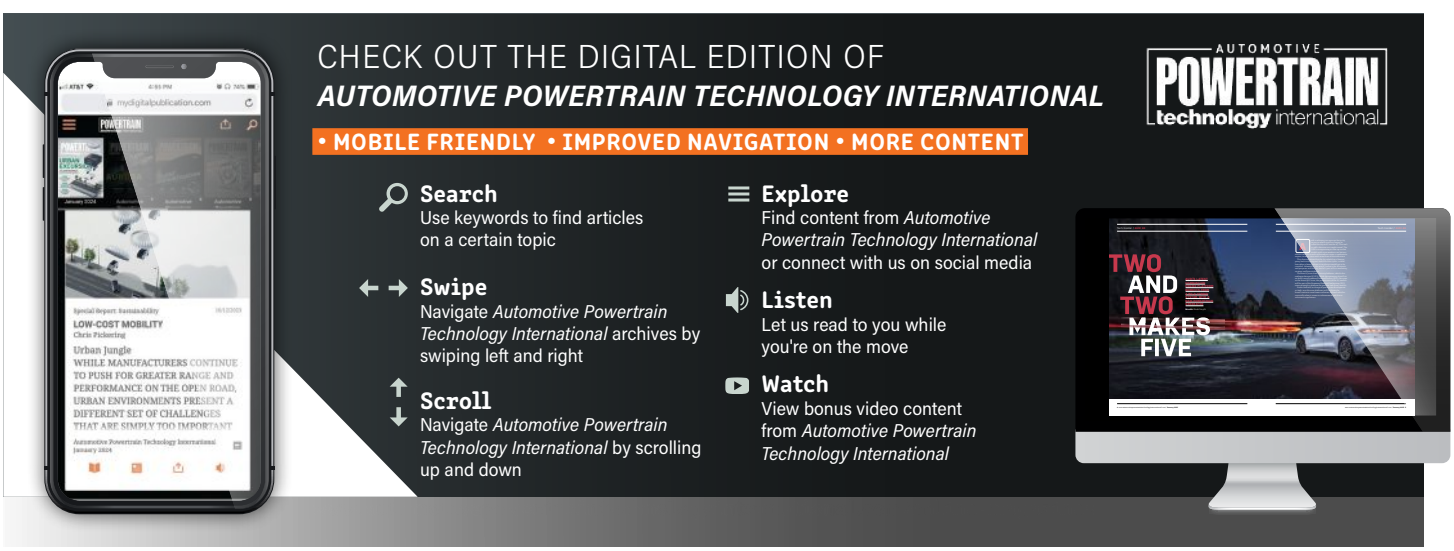
https://www.pickeringtest.com/solutions/simulation/pxi-based-battery-management-system-test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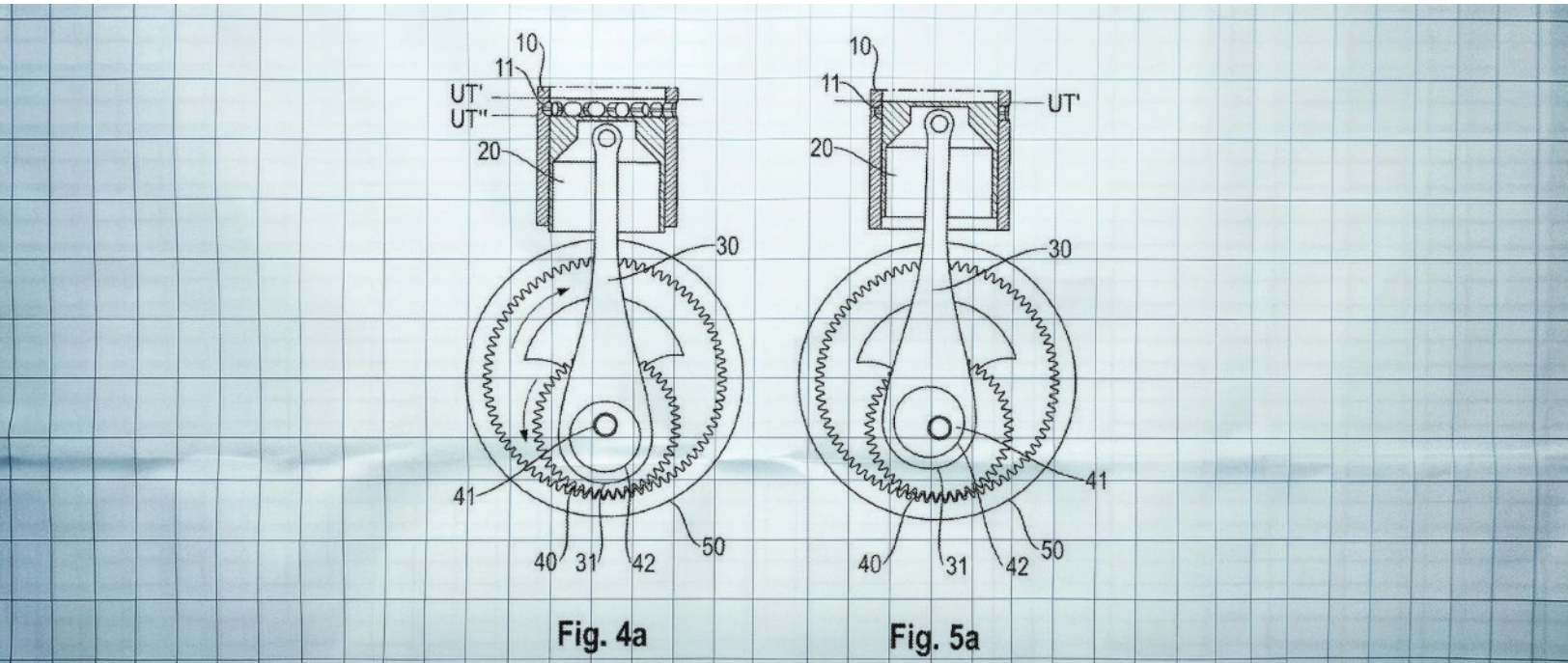

Different strokes

PORSCHE'S PATENT FOR A SIX-STROKE ENGINE SHOWS INNOVATION IS STILL ALIVE AND KICKING IN THE WORLD OF ICE

Words: Lawrence Butcher

Automotive manufacturers file patents all the time. Often, they are for ideas or designs that never see production – the companies are simply securing the IP for potential future use. However, sometimes a particularly interesting patent lands, and Porsche's latest filings in the USA contain one such curio – a concept for a six-stroke engine or, as the Porsche puts it, two times three strokes.

The benefits of the two-stroke engine are well known, not least that you get a power stroke every revolution of the crank. However, and despite the efforts of many developers, they are hard to make clean enough to meet emissions regulations. Four-strokes obviously have their own advantages and Porsche's patent seeks to combine the best of both worlds, by adding a third stroke to each firing sequence.

The engine has a traditional intake and compression stroke, but at the end of the expansion stroke fresh charge air is mixed with the remaining exhaust and fuel added, before a second firing event, expansion stroke and finally exhaust.

To achieve this, the concept features traditional poppet valves and ports around the base of the cylinder. These ports are only 'open' at the bottom of the first power stroke, which has a different length from the other five, achieved through the use of a planetary gear system around the crank, providing the variable stroke. Obviously, this increases the complexity of the powertrain, but with the benefits of reduced emissions due to the more complete burning of the mixture and increased power.

Though more complicated than a traditional crank and rod combination, it would be fair to say that Porsche's approach is simpler than those mooted by other OEMs for achieving a variable stroke.

For example, back in 2018, Infiniti presented a production-ready variable compression ratio engine, which relied on a complex multilink system with a control shaft and actuator to change the effective stroke of the crankshaft. Though not exactly widespread in its use, the company's VC-Turbo engine (as the variable-compression-equipped engines were dubbed) has made it into production in the QX series of SUVs.

Around the same time as Infiniti, Honda also patented a variable compression ratio system, which relied on hydraulic actuators in the connecting rods.

Moving up to date, there are certainly visual similarities between the geared crank layout in Porsche's patent and the variable compression ratio system developed by Dutch firm Gomecsys, though Porsche's differs in its detail and the fact that it is part of the larger six-stroke concept.

Gomecsys, meanwhile, has focused its efforts on implementing its design in mass-production motorcycles. With an ability to vary the compression ratio between 9.5:1 and 15:1, it has the potential to net considerable fuel and CO_2 reductions.

Whether Porsche's engine will ever see production remains to be seen, but the OEM has committed to ICE power in its performance models for the foreseeable future. Could this be the route to ensuring compliance with ever-tightening emissions regulations? What is certain is that development of new powertrain technologies is not limited to the EV space, and the 2020s are proving to be a hotbed of innovation across the board.

AUTOMOTIVE ELECTRONICS
APPLICATION GUIDE

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A GUIDE TO SELECTING THE RIGHT PARTS FOR YOUR AUTOMOTIVE APPLICATIONS

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